
LONG PAPERS

Editors: M. Qhobela, M. Ntsohi & L.G. Mohafa

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The reviewers’ suggestions were considered by the members of the Review Panel. Where there was consensus, the reviewers’ recommendations were accepted by the Review Panel. Where consensus was not reached, the Review Panel appointed at least one other reviewer and all reviews were taken into consideration before a decision was made.

In cases where papers were accepted with conditions, authors were guided to make changes in order to have their papers accepted, or provide a compelling argument for no further revision.

Long papers that were re-worked and re-submitted by authors underwent a final review and editing process before being published in the accredited Book of Proceedings.
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Long paper: Maximum of 6000 words, including references, for a 30-minute pre-recorded, narrated presentation. Long papers are equivalent to journal publications utilising the same criteria as AJRMSTE articles and are reviewed accordingly. In accepting a long paper for presentation at the SAARMSTE conference, the Review Panel presumes:

1) The paper is original and has not been published elsewhere;
2) Permission will be granted by the author for the accepted long paper to be published in the accredited Book of Proceedings;
3) At least one of the authors will register and attend the conference to present the paper;
4) First authors will only present one long paper at each conference.

Long papers are fully peer reviewed and thus attract Department of Higher Education and Training subsidy.

Short paper: Maximum of 1500 words, including references, for a 20-minute pre-recorded and narrated presentation. Short papers should highlight preliminary findings and significance of the research. Short paper submissions could be the first draft of a journal article consisting of: abstract, introduction literature review, methodology, results and conclusions. Authors are encouraged to submit short papers for development of an article at the post conference workshop. After acceptance of the 1500 word short paper, authors may elect to develop their research further into a 3600 word paper which will NOT be reviewed but, after consultation with the editor, could appear in the electronic record of Research Papers in Mathematics, Science and Technology Education. Short papers are not eligible for DHET subsidy.

Snapshot paper: Maximum of 1500 words, including references, for a 10-minute pre-recorded and narrated presentation. Snapshot papers should be based on emerging research, not necessarily with results, but with a framework of: abstract, introduction, literature review, methodology and the way forward.

Guided poster: Maximum of 1500 words, including references, for a 10-minute pre-recorded poster with some narrated, descriptive text. An outline of the main features of the author’s research which will be reported on in the content of the poster presentation.

Symposium / panel paper: Maximum of 1500 words, including references, for a 90-minute pre-recorded and narrated team discussion around issues where different points of view, approaches, debates or analysis of the same problem are presented. The paper should contain details of each speaker’s contribution and how these come together to create a forum for debate. This is not a forum for the presentation of multiple short papers. The emphasis is on exchange of ideas and discussion.

Short papers, snapshots, posters and symposia papers should appear in the 2021 electronic record of Research Papers in Mathematics, Science and Technology Education. These are not fully peer reviewed and thus do not attract Department of Higher Education and Training subsidy.
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A GLIMPSE INTO THE MATHEMATICAL READINESS OF STUDENTS UNDERTAKING A UNIVERSITY THIRD-YEAR MATHEMATICS MAJOR
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Abstract
This paper reports on empirical results about the mathematical readiness of students undertaking a university third-year mathematics major. These students are expected to have a substantial level of mathematical background upon entering their third-year Real Analysis mathematics studies. By virtue of time constraints in this module, it is not always possible for the lecturer to comprehensively summarise knowledge that is considered prerequisite for the module. However, for students who are unable to recall this prerequisite knowledge or who have knowledge gaps in this regard, this can be a substantial stumbling block. A group of 81 students were exposed to a carefully planned diagnostic test focusing on the key knowledge components in the Real Analysis module. Descriptive statistics were used to analyse students’ work. The results show potential stumbling blocks for students and, at the same time, develop possibilities for educators to remedy students’ deficiencies and increase study success.

Introduction
Success in studying mathematics modules at university level often relies largely on prior knowledge of the mathematics that precedes the module. During the last decade many researchers (nationally and internationally) contributed towards a lively discussion regarding students’ preparedness, knowledge gaps and study success, but most of these discussions are restricted to university beginners (du Plessis & Gerber, 2012; Greefrath, Koepf & Neugebauer, 2017; Rach & Heinze, 2017). Following this discussion other studies focus on suitable methods (like entrance tests) to identify possible knowledge gaps or students at risk (e.g., Durandt, Blum & Lindl, in press; Durandt, 2019; Hailikari, Nevgi & Lindblom-Ylänne, 2007; van Appel & Durandt, 2019). Prior knowledge in pure mathematics modules is particularly important for students majoring in the mathematical sciences since the building blocks from the pre-tertiary environment and the tertiary environment are essential for students to follow logical arguments in more advanced mathematics modules and in post graduate studies. This paper reports on an investigation about the mathematical readiness of students undertaking a university third-year mathematics major.

The results might be useful to transform instruction to adequately support students, to streamline the diagnostic test and for research purposes. Accordingly, our research questions are:

(1) In what content areas, required for studying a mathematics major Real Analysis, can knowledge gaps be identified? and (2) Can these content areas have a possible influence on quality teaching and learning?
Theoretical framework

In general, researchers agree on the importance and influence of prior knowledge in the construction of new understanding (e.g., Hailikari et al., 2007) and specifically the effect on learning mathematics (e.g., Rach & Heinze, 2017; Weinert, 1989). Research has shown that domain-specific prior knowledge especially influences student achievement (Dochy, 1994), although some might argue that this is not the case in all domains. It seems that individual differences in the prior knowledge base have an effect on student achievement and on teaching and learning (for a more complete summary of the literature, see Hailikari et al., 2007). These differences might be related to incomplete or inaccurate prior knowledge. In this study we argue that incomplete or inaccurate prior knowledge has an influence on student achievement, specifically in mathematics majors, and might hinder the learning of more advanced mathematics. Therefore, if educators have ‘tools’ to identify possible misconceptions or gaps early in the academic semester, these might be addressed through instructional support. This is particularly relevant for quality teaching and learning.

The basis for prior knowledge assessment (e.g., entrance or diagnostic test) should consider what type of knowledge is the focus of the assessment (Hailikari et al., 2007). Many years ago researchers distinguished between declarative, procedural, and conditional knowledge. Different types of knowledge and cognitive processes are aligned with Bloom’s taxonomy (Anderson & Krathwohl, 2001) and this asks for different types of questions. According to Dochy (1992) prior knowledge includes declarative and procedural knowledge. He viewed declarative knowledge as the accumulation of facts and concepts that comes to the surface by recognition or reproduction, while procedural knowledge comes to the surface in assessment through production or application. It seems that different assessment measures activate different kinds of prior knowledge and examples for such studies are discussed in Hailikari et al. (2007). According to Greefrath et al. (2017), tests (similar to an entrance or diagnostic test) at the start of studies can have distinct functions: (i) the aim of recording the current performance level of students, or (ii) generating a prediction of how successful students will be. These tests might be optimized to improve the prediction of study success, but perhaps also to use different measure to produce different types of prior knowledge.

Success in mathematics modules might rely largely on prior knowledge components, but research has also shown the effect of quality teaching (Schlesinger, Jentsch, Kaiser, König & Blömeke, 2018; Schoenfeld, 2014). Although we were interested in identifying knowledge gaps in mathematics students studying a mathematics major, we were guided by the framework for quality teaching as highlighted in Blum (2015). These classifications suggested criteria for quality teaching that are applicable for the secondary and the tertiary environments. In the following, we describe four of these criteria briefly:

a) Effective classroom management - the criterion comprises aspects such as structuring lessons clearly; using time effectively; separating learning and assessment recognisably; avoiding disruptions; including varying methods and media flexibly.

b) Student orientation - this criterion contains aspects such as progressing adaptively; linking new content with students’ pre-knowledge; using language sensibly; giving diagnose, feedback
and support individually; using students’ mistakes constructively as learning opportunities; encouraging individual solutions of tasks.

c) **Cognitive activation of students** - this means stimulating students’ mental activities by maintaining a continual balance between students’ independence and teacher’s guidance. A key element for realising that balance are adaptive teacher interventions which allow students to continue their work without losing their independence.

d) **Meta-cognitive activation of students** - this means stimulating accompanying and retrospective reflections about students’ own learning; advancing learning and working strategies.

**Methodology**

In this study we followed a pragmatic approach (Creswell, 2013) as we were seeking for practical solutions. With knowing the advantages of identifying knowledge gaps at the beginning of the academic semester for both students and educators (Hailikari et al., 2007), and the intention to follow the guidelines for quality teaching (Blum 2015), also at the tertiary level, the overarching aim of this study is to identify possible knowledge gaps in third-year mathematics students majoring in a Real Analysis module.

**Participants**

There were 90 students in the module at the time of the diagnostic test, of which 81 students participated. The other students either chose not to participate or were absent on the day. The absentees were not considered when analysing the data. Participants are third-year mathematics students at a large public university in South Africa. They are majoring in mathematics and it is compulsory to enroll for the Real Analysis module to complete their BSc degree.

**Research design and data collection instrument**

The content areas of the Real Analysis module include: *The Archimedean Property, Intervals, Sequences, Limits of Functions,* and *Continuity* (Bartle & Sherbert, 2011). Many of these concepts are familiar to the students as they are taught these basic principles in their first and second year of their mathematics studies, and some topics (e.g., intervals and sequences) are already introduced at secondary school level although very basically. The purpose of Real Analysis is to revisit these concepts, but to do so in a much more rigorous and mathematically mature manner. The module is devoted to theoretical proofs and the development of techniques and strategies to formally prove answers that students would simply have calculated in previous years. It is therefore significant for students to have a firm recall of their prerequisite knowledge. Several years of teaching this module has made the first author of this paper aware that students of this module appear to have knowledge gaps. The intention behind this investigation was to identify possible problem areas, obtain some indication of the impact thereof on student performance in the module, so that educational intervention strategies could be designed to be implemented in the current and subsequent years. Table 1 illustrates how the Real Analysis module is structured over the 14 weeks of the semester.
Table 1. The first semester structure of the Real Analysis module.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Content</th>
<th>Week(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>Sets and Functions, Mathematical Induction, Finite and Infinite Sets</td>
<td>Week 1 (a very brief introduction to the core ideas necessary for the module, that students have already been exposed to)</td>
</tr>
<tr>
<td>2*</td>
<td>The Algebraic and Order Properties of Reals, Absolute Value and the Real Line, The Completeness Property of Reals, Applications of the Supremum Property, Intervals</td>
<td>Weeks 1 – 4</td>
</tr>
<tr>
<td>3*</td>
<td>Sequences and Their Limits, Limit Theorems, Monotone Sequences, Subsequences and the Bolzano-Weierstrass Theorem, The Cauchy Criterion</td>
<td>Weeks 4 – 8</td>
</tr>
<tr>
<td>4*</td>
<td>Limits of Functions, Limit Theorems</td>
<td>Weeks 8 – 10</td>
</tr>
<tr>
<td>5*</td>
<td>Continuous Functions, Combinations of Continuous Functions, Continuous Functions on Intervals, Uniform Continuity</td>
<td>Weeks 10 – 14</td>
</tr>
</tbody>
</table>

*Chapter numbers and content areas aligned with the prescribed textbook (Bartle & Sherbert, 2011, p. xi)

In each week there are two different (45 minute) lecture periods, and a double (90 minute) tutorial class. Students will typically write three class tests (in Weeks 3, 8 & 12) and two semester tests (in Weeks 5 & 10). At least three hours of consultation are made available to students every week (during office hours), and a dedicated e-mail address is provided to students so that they can seek assistance after-hours (this additional consultation opportunity is not standard procedure and an additional effort from the module lecturer). Following the guidelines for quality teaching (Blum, 2015) the module lecturer oriented the teaching in the following way:

a) **Effective classroom management:** students are given a clear outline of the plan for the week at the start of the week; all official class time is used; assessments are typically scheduled outside of class time so that teaching time is not lost; typed-out slides are displayed via a projector, and a document camera is used to write out additional notes (e.g., comments, examples, and proofs of theorems).

b) **Student orientation:** each lecture begins with a recap of the previous work done, and ends with a summary of the key ideas; the schedule for the course is used as a guideline only, as often it is clear that students require more time on a section, and then additional time is allocated wherever possible; the appropriate mathematical language is used throughout the session; students are encouraged to participate; regular pauses occur during the lecture where students are asked to “vote” on their instincts, or knowledge regarding a particular mathematical result. Students are encouraged to attend consultation sessions and during the tutorial classes time is allocated for the lecturer to walk to individual students whilst they are working on the problems.
c) & d) Cognitive and meta-cognitive activation of students: examples and exercises are physically discussed and written out in class, and the thought pattern or strategy is explained so that students are exposed to various techniques and strategies rather than a recipe-style approach to solving problems. Students are encouraged to explore their own techniques during the tutorial classes and consultation sessions; and the student’s approach to solving a question is first considered and thereafter guidance is given accordingly.

In this study, the participants were exposed to a diagnostic test in February 2020, the beginning of the first semester (Week 4) of their third-year. The students were given 20 minutes to complete the test during an official time slot and they were instructed to write their answers on the printed page in the spaces provided. The evaluation of the test was limited to answers only (apart from the last question), as the answers to the questions did not require any detailed computation. The use of a calculator was not permitted. The diagnostic test consists of five sections, altogether nineteen items with twenty-two marks. Section A (on Set Theory) had four items; Section B (on Inequalities and Absolute Values) had seven items; Section C (on Limits of Sequences) had five items; Section D (on Limits of Functions) had three items; and Section E (on Modelling) had one item worth three marks. The construction of the test was carefully discussed between the experienced module lecturer (the first author), a mathematics education specialist and another subject specialist, and it was specifically designed for this project. The test items were confirmed valid between all specialists. Sections A – D correspond directly with the content of the Real Analysis module (Bartle & Sherbert, 2011) and Section E was included with the intention to test students’ ability to transfer from one topic area to another and provide a possible suitable solution for a real-life situation (this transfer of knowledge is about situated cognition, see the criteria from Blum in the second section of this paper). Furthermore, the construction of the test and the inclusion of the last section on modelling were informed by a diagnostic test, with a similar design, used in another module in 2019 and 2020 at the same university (see Durandt, 2019; Durandt et al., in press).

A detailed description of the different sections of the diagnostic test are (see Figure 1 for examples of items):

(i) **Section A** - these questions focus on particular basic set theory concepts taught in first-year mathematics (see Stewart, 2016). For an illustration of the items see Figure 1a. Question 1 requires students to be comfortable with applying the operations of union and intersection to sets, and on a subtle level, to be aware of the order in which these operations should be performed. Question 2 tests some basic set-theoretic notation. It is clear that the notation \( A \subseteq B \) is not appropriate for sets (without defining an ordering on the sets) in part (a). Similarly, we have that \( x \in C \) but \( x \) is not a subset of \( C \) for part (b).

(ii) **Section B** - the focus was primarily on inequalities, absolute values, and inequalities involving absolute values (although there was also a question not directly related to these areas). For an illustration of the items see Figure 1b. If we consider Question 1(a), this question tests, in an abstract context, whether or not reciprocals reverse an inequality in all cases. At face value this may appear to be true, but it is clearly false in this general context (consider, for example, \( a = -1 \) and \( b = 1 \)). We have a similar
situation for \( (b) \), but in a somewhat more concrete context, as we test if reciprocals preserve inequalities in general. This is fairly obviously false (if one considers \( x = 0 \) this isn’t even possible). \( (c) \) is naturally true, as an instance of an absolute value applied to a function \( f(x) = x - 1 \) and its negative. On a slightly more technical note, one notices for \( (d) \) that the images of \( f(x) = \frac{x^2 - 9}{x + 3} \) are the same as \( g(x) = x - 3 \) for all values of \( x \) in the domain other than \( x = -3 \) (where \( f \) fails to exist, but \( g(-3) = -6 \)). The answers to Question 2 \( (a) \) and \( (b) \) are immediate (namely \( (-\infty, 1] \cup [3, \infty) \) and \( (-\infty, -\frac{3}{2}] \)) if one considers an expression of the form \( |a - b| \) as the distance of \( a \) away from \( b \). The geometric interpretation of the absolute value provides valuable insight into the nature of this function. \( (c) \), on the other hand, tests a technical aspect when working with an exponential base on the interval \( (0, 1) \) (namely the reversal of the inequality, to obtain \( (-\infty, -\frac{1}{\ln 2}) \)).

\( (iii) \) Section C - this section tests some limits of sequences. For an illustration of the items see Figure 1c. The sequences tested are fairly routine problems that are discussed in a second-year module (Sequences and Series), where an entire semester is dedicated to the development of this theory (see Stewart, 2016). A natural observation with regard to sequences is the following: a sequence that is of the form of a rational function in \( n \), where the degree of the numerator and denominator in \( n \) are the same, will converge to the ratio of the leading coefficients, and so for Question 1 this limit would be \( -\frac{2}{3} \). In the case of Question 4, it is clear that the growth rate of the denominator is substantially higher than the growth rate of the numerator, with the result that the sequence will converge to 0 overall. Clearly the limits of the sequences in Question 2 and Question 3 do not exist (although some students indicated that the sequence for Question 3 has a limit of \( \infty \), for which they received 0.5 marks). Finally, Question 5 is Euler’s sequence, with limit \( e \).

\( (iv) \) Section D – this section considers limits of functions. For an illustration of the items see Figure 1d. The limits of these functions are considered in a first-year mathematics module (see Stewart, 2016). Question 1 can be computed in several ways, but the most elegant solution involves factoring the denominator into a difference of squares, to arrive at a limit of \( \frac{1}{4} \). Obviously, the limit for Question 2 doesn’t exist. Finally, Question 3 involves a subtle observation that when extracting the \( x^2 \) from the square root one is left with the scenario of \( \sqrt{x} = |x| \), and in this case since \( x < 0 \) we have (after cancellation) that a negative is introduced to arrive at a final limit of \( -1 \). Although students are exposed to this scenario in their first year of study, it is a technical detail that is often overlooked by students.

\( (v) \) Section E – this last section includes a question on mathematical modelling where the approximate volume of a hot air balloon has to be calculated based on a photo. For details of the task view Blum and Borromeo Ferri (2009).
### Questions from Section A

1. If $A = \{1, 2, 3\}$ and $B = \{2, 7, 9\}$ determine
   
   (a) $(A \cup B) \cap B =$  
   (b) $(A \cap B) \cup B =$

2. True or false (circle the appropriate answer):
   
   (a) If $A = \{1, 2, 3\}$ and $B = \{1, 2, 3, 4\}$, then $A \leq B$. 
   (b) If $C = \{x, y, z\}$, then $x \leq C$.

### Questions from Section B

1. True or false (circle the appropriate answer):
   
   (a) If $a, b \in \mathbb{R}$ and $a \leq b$ then $\frac{1}{a} \leq \frac{1}{b}$. 
   (b) If $x \in \mathbb{R}$ and $x \leq 2$ then $\frac{1}{x} \leq \frac{1}{2}$. 
   (c) If $x \in \mathbb{R}$ then $|x - 1| = |1 - x|$. 
   (d) If $x \in \mathbb{R}$ then $\frac{x^2 - 9}{x+3} = x - 3$.

2. Write the following in interval notation:
   
   (a) $\{x \in \mathbb{R} : 1 \leq |x - 2|\} =$  
   (b) $\{x \in \mathbb{R} : |x - 1| < |x - 2|\} =$  
   (c) $\{x \in \mathbb{R} : \left(\frac{3}{4}\right)^x > e\} =$

### Questions from Section C

1. $\lim_{n \to \infty} \frac{2n}{1-3n} =$  
2. $\lim_{n \to \infty} (-1)^n =$  
3. $\lim_{n \to \infty} (n) =$  
4. $\lim_{n \to \infty} \left(\frac{2n}{3}\right) =$  
5. $\lim_{n \to \infty} \left(\frac{1 + \frac{1}{n}}{n}\right)^n =$

### Questions from Section D

1. $\lim_{x \to 4} \frac{\sqrt{x} - 2}{x - 4} =$  
2. $\lim_{x \to 1} \frac{1}{x - 1} =$  
3. $\lim_{x \to -\infty} \frac{\sqrt{x} + 1}{x} =$

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**Figure 1.** Example items of the diagnostic test (a) Section A on Set Theory, (b) Section B on Inequalities and Absolute Values, (c) Section C on Limits of Sequences, and (d) Section D on Limits of Functions

Additionally, three non-mathematical questions were included at the beginning of the test (but did not form part of the assessment), to get a feel for students’ perception of the module, and a self-assessment of time allocated to the module.

The implementation of the test and the collection of data went according to plan. Standard ethical protocol was followed. The last question (Section E) was an open-answered item that involved a greater potential for a subjective mark to be allocated to a student. To this end the authors marked this question independently (but used a generally agreed upon mark scheme).

A calculation was performed to determine Cohen’s Kappa (Cohen, 1960): a statistic which measures the reliability between two markers. In total, 10 participants gave responses to this question, and the Kappa value was calculated to be 0.74, which is considered satisfactory.

**Results**

The data from the test was captured in Microsoft Excel 2016, and all the represented statistics and graphs were created in this environment. Each of the mathematics questions were calculated as a 1, 0 response (1 being a correct response and 0 being an incorrect response) to a specific question (apart from the modelling question in Section E). The totals for individual questions, as well as for each section, were calculated as a percentage of the 81 participants. A column
chart was used to represent the average percentage (per section) of correct versus incorrect answers (see Figure 2a); and later to represent the percentage (per question) of correct versus incorrect answers (see Figure 3). The histogram below (see Figure 2b) indicates the distribution of student marks as percentages for the test as a whole (excluding Section E).

Figure 2. (a) Correct and incorrect answers for the diagnostic test summarized per section; and (b) a histogram of student mark distribution.

Figure 2a and Table 2 illustrate the performance of students per section of the test. It is clear that Section A (on Set Theory) was the best answered section overall (with an average of 61%), followed closely by Section C (on Limits of Sequences). Section D (on Limits of Functions) was answered the most poorly (with an average of 23%), followed fairly closely by Section B (on Inequalities and Absolute Values). The questions in Section B and Section D required more technical knowledge than those in Section A and Section C (where basic understanding was primarily being assessed) - the results seem to support this observation. Figure 2b gives an indication of the overall performance scores of students – it is clear that the majority of students performed poorly in the test overall. The histogram is positively skewed and, in opposition to our expectations, very few students received total scores above 60%. In terms of the results for the last section on modelling: the average for this question was only 3%, which may be attributed to the idea that students find it difficult to transfer knowledge from one topic area to another and to provide a suitable solution for an unfamiliar real-life situation.

Table 2. The average (per section) percentage of correct answers

<table>
<thead>
<tr>
<th>Sections</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set Theory</td>
<td>61</td>
</tr>
<tr>
<td>Inequalities and Absolute Values</td>
<td>31</td>
</tr>
<tr>
<td>Limits of Sequences</td>
<td>59</td>
</tr>
<tr>
<td>Limits of Functions</td>
<td>23</td>
</tr>
</tbody>
</table>

Figure 3a shows the results per question for Section A. One would imagine that only a few students would not have answered Question 1(a) and (b) correctly, particularly since this was
not asked in an abstract manner - but only 78% and 83% of students answered (a) and (b) (respectively) correctly. Alarmingly, for Question 2 (a) and (b) less than 45% of students answered these questions correctly. In summary, most students seem to be comfortable with basic unions and intersections. On the other hand, most students appear to have knowledge gaps when it comes to set containment and differentiating between the elements of the set and the set itself (less than half the students got this correct).

Figure 3b shows the results per question for Section B. Question 1 (b) and (c) were reasonably well answered, with approximately 80% of students faring well in these questions. On the other hand, 15% or less of students were able to answer each of the other questions correctly (Question 1 (a) & (b)). In particular, the whole of Question 2 was very poorly answered with at most 10 students out of 81 answering each question correctly, and only 4 students answering Question 2(b) correctly. Students seem comfortable with reversing inequalities for reciprocals and the basic idea of absolute values. However, they seem to apply the reciprocal rule blindly (as well as the cancellation property). Students have difficulty with the geometric properties of the absolute value, and blindly applying multiplication and division to inequalities.

Figure 3c shows the results per question for Section C. Note that a score of 0.5 was possible for Question 3 and so the score for this question can rather be seen as total of 52 out of 81. A quarter of the students claimed (incorrectly) that the sequence in Question 2 converges, which is quite surprising. Approximately a third of students were not comfortable with each of the questions Question 1, 4, and less than a quarter of students knew (or could establish) the special limit for Question 5. In general, it was apparent that students had significant gaps in their knowledge of sequences, as these were mostly rudimentary questions.

The results of Section D (per question) are displayed in Figure 3d. In a rather surprising outcome, less than half of the students correctly answered Question 2. Moreover, only 16% of students correctly answered the first question, and only 3 students (approximately 4%) were able to correctly answer Question 3. The general indication was that students again had gaps in terms of their understanding of the basic limits of functions, and hence also the more technical question.
Figure 3. Correct and incorrect answers for the diagnostic test per question in (a) Section A (Set Theory), (b) Section B (Inequalities and Absolute Values), (c) Section C (Limits of Sequences), and (d) Section D (Limits of Functions)

The modeling question (in Section E) was allocated a total of 3 marks. Only 10 students had purposeful attempts for this question and, of those attempts, the highest result was 1.5 (which was attained by three of the ten students).

**Discussion of findings**

**Importance of the assessment of prior knowledge**

In this study we argued that incomplete or inaccurate prior knowledge has had an influence on student achievement, specifically in mathematics majors, and might hinder the learning of more advanced mathematics. To demonstrate this aspect, we identified some questions from the prescribed textbook, to link the questions from the questionnaire with student’s work. We only investigated two examples, but these might be expanded and reported on in a further study.

As a first example, we note that set theory forms part of the foundation of any module in pure mathematics, and since Real Analysis is dedicated to the formal and rigorous development of the study of the real numbers, there are many key elements of set theory that underlie it. Consider, for example, students who are not comfortable with set-theoretic notation (such as the notation tested in Section A, Question 2 from the diagnostic test), frequently encounter difficulties when faced with proving statements regarding the infimum\(^1\) and supremum of a set. This is shown in Figure 4 where a student responded accordingly.

**Figure 4. An example showing a student’s lack of prior knowledge in set theory**

\(^1\) These are standard terms in pure mathematics
It is apparent that this student (in Figure 4) wants to compare the infimum and supremum of the set with the members of the set, but instead the student consistently relates these real numbers to the sets $A$ and $B$ directly (but the elements of the set and the set itself are not comparable). The student appears to have a reasonable understanding of the notions of the infimum and supremum of a set, and so their downfall is not specifically related to the content of the module, but rather their understanding of how members of a set relate to the set itself, which is prior knowledge to the Real Analysis module.

As a second example, very low results were recorded for Section B on inequalities and absolute values. Whilst this is taught at secondary level and reiterated and extended at first-year level, these notions remain a stumbling block for many students majoring in mathematics. Although these concepts are not tested directly in the Real Analysis module, a lack of mastery of these concepts in preceding modules, produces unfavourable consequences. Consider, the response by a student shown in Figure 5.

\[
\begin{align*}
|\varepsilon - c| &< \frac{\varepsilon - 1}{2} \\
\frac{\varepsilon - 1}{2} &< \varepsilon - c < \frac{\varepsilon - 1}{2} \\
\frac{\varepsilon - 1}{2} &< \varepsilon < \frac{3\varepsilon - 1}{2} \\
\frac{\varepsilon - 3}{2} &< |\varepsilon - 1| < \frac{3\varepsilon - 3}{2} \quad \varepsilon > 1
\end{align*}
\]

**Figure 5. An example showing a student’s lack of prior knowledge in inequalities and absolute values**

Apart from some issues with the calculations in moving from lines 2 to 3, we notice that in line 4 the term on the left of the inequality is negative for some values of $c > 1$ whilst the term on the right is positive for all $c > 1$. The student has applied absolute values to this inequality without taking this into consideration, and hence arrived at a false conclusion. This is one such example of a typical mistake made by third-year students in this module. This evidence is mirrored by the poor results for Section B.

Both examples show how a lack of domain-specific prior knowledge has had an adverse effect on the construction of new understanding, which is related to the findings from Dochy (1992). The overall average for the diagnostic test is also lower than expected, and so the module lecturer might consider the implementation of the test right at the beginning of the semester, and not only in the fourth week, to record students’ performance levels earlier and act accordingly. This would also be more aligned with the suggestions from Greefrath and colleagues (2017). Although in some areas (Set Theory and Limits of Sequences) the prior knowledge of students appears stronger than in other areas (Inequalities and Absolute Values,
Limits of Functions and Modelling), still findings show declarative and procedural knowledge gaps (Dochy, 1992).

Consequences for quality teaching and learning

The module lecturer strives for quality teaching, and therefore this study might suggest some strategic changes to eliminate the effect of incomplete or inaccurate prior knowledge on the learning of mathematics in the Real Analysis module. Based on the aforementioned framework for quality teaching (e.g. section 2), and specifically in the interests of an improved student orientation, it is demonstrated from the two abovementioned examples (see section 5.1) that more time needs to be spent to make sure that students have the required pre-knowledge. Although time is already allocated in the first week of the module to revise some of the notions of set theory, it is clear that this allocation is insufficient. In this study unsatisfactory results were reported even after this revision period.

In addition to the issue of time-allocation, is the concern regarding the kind of strategic support sufficient to eliminate these domain-specific content gaps. Although common mistakes (such as those discussed in section 5.1) are highlighted to students during the lesson, in an attempt to try to mitigate the reoccurrence of these mistakes, it may be beneficial to dedicate an entire lecture to these mistakes stemming from prior knowledge gaps. For example, allowing students to manipulate absolute inequalities on their own, and subsequently to illustrate to the students with examples why this may lead to mathematical irregularities. In this way students can explore first-hand how and why these mistakes arise in their own solutions. This could be a way in which students may be guided away from these pitfalls by adaptive teacher interventions.

Another concern is the meta-cognitive activation of students, as the results show that although some content areas (e.g., Inequalities) have already been addressed at secondary and early tertiary level too many mathematics students still struggle with these at third-year level. Have the strategic educational efforts in previous years then paid off? Have students required sufficient learning and working strategies? This aspect might be considered in a broader approach to improve quality teaching and learning.

Conclusion

The purpose of this study, carried out in 2020, was to identify the mathematical readiness of students undertaking a university third-year mathematics major, Real Analysis, and to identify possible knowledge gaps that might hinder quality teaching and effective learning of new concepts. This study was informed by theory confirming the advantages of identifying knowledge gaps at the beginning of the academic semester for both students and educators (Hailikari et al., 2007), and the intention to follow the guidelines for quality teaching (Blum 2015) at the tertiary level. The 81 students were expected to have a substantial level of mathematical background upon entering their third-year Real Analysis mathematics studies, but the overall results indicate the contrary. In all content areas students performed on average lower than expected, although in Set Theory and Limits of Sequences the prior knowledge of students appears stronger than in the areas of Inequalities and Absolute Values, and Limits of Functions. There is certainly a big potential for further improvement.
By virtue of time constraints in this module, it is not always possible for the lecturer to comprehensively summarize knowledge that is considered prerequisite for the module (e.g., Inequalities). However, for students who are unable to recall this prerequisite knowledge or who have knowledge gaps in this regard, this can be a substantial stumbling block. In retrospect it might be useful to transform instruction to adequately support students, although this could not be implemented in 2020. One possibility is to expose students to intensive revision sessions before the start of the Real Analysis module.

From a normative point of view, the authors expected third-year mathematics students to be able to transfer knowledge from one topic area to another and to provide a possible suitable solution for an unfamiliar real-life situation. Although the participants were only exposed to one such example, the idea of situated cognition might be further investigated in the Real Analysis module.

The authors’ intention is to repeat the study in 2021 and compare the diagnostic test results with the 2020 cohort. These results might also be used as a covariate for student performance in other formal assessments, similar to other studies (Durandt et al., in press). This might also lead to a refinement of the diagnostic test.

References


Abstract

This paper presents results from a design research study into the design of a conceptual framework, learning activities, assessment processes and teaching programmes for the development of mathematical thinking in preservice, Primary Education students. It reports on data from a particular implementation of this design - a module teaching fundamental mathematics to preservice, primary education students. The module aimed to generate a positive experience of mathematical thinking, to counter students’ possible, past experience of mathematical learning that may have been rigid and formulaic. The module required students to engage with mathematical content in an extended way, emphasizing the importance of meaning making and reasons in mathematics. Three different response modes were included in tutorials and assessment: compact, visual and elaborated. The paper presents and compares summary results of an initial benchmark, a midyear and a final assessment, for each of the three response modes, as well as for three mathematical topic categories in the compact mode. The results show an appreciable and significant improvement in student performance in each of the three modes and for each of the three topic categories. This suggests that this design may prove effective for developing students’ mathematical thinking.

Introduction

The poor state of mathematics education in South Africa has been an area of concern for a number of years (Taylor, 2011; Spaull, 2013). Even though the Annual National Assessments have been called into question, the mathematics results of these tests over grades 4 to 6, for the years 2012 to 2014 (van der Berg, 2015) indicate that weaknesses in the system extend to these grades. This is supported by the findings of the international TIMSS 2011 Assessment study, that, in South Africa, “three quarters (76 per cent) of Grade Nine pupils in 2011 still had not acquired a basic understanding about whole numbers, decimals, operations or basic graphs,” (Spraull, 2013, pg. 4).

In response to these results, a number of studies on Primary teacher content knowledge have been carried out (Carnoy & Chisholm, 2008; Venkat & Spaull, 2015). These generally identify gaps in teachers’ mathematical content knowledge, including some mathematical topics taught in these grades. Following this, the South African department of Higher Education and Training (DHET) constituted the Primary Teacher Education (PrimTED) project, which has as one aim, the research and development of Mathematics education in Primary Preservice education programmes in the country. The aim of this project is to formulate conceptual frameworks and standards to deepen the teaching of mathematical content knowledge in primary preservice education programmes in South Africa (Brown, Mc Auliffe, & Lampen, 2018).
Working in preservice teacher education programmes is a promising approach (Ma, 1999), which aims at addressing the identified weaknesses in teacher mathematical content knowledge (Venkat & Spaull, 2015) by ensuring that this is not the case in newly qualified teachers. To do this, it is necessary to challenge students’ prior experience of mathematics, which often has involved the rote learning of meaningless symbolic forms and constructions (Kilpatrick, Swafford & Findell, 2001). Many school teaching approaches that blend more complex mathematical activity into the classroom have been developed (Niss, Bruder, Planas, Turner & Villa-Ochoa, 2016) and many of these have shown a positive impact on mathematical learning such teaching (Niss & Høgjaard, 2019; Schoenfeld, 2007b; van den Heuvel-Panhuizen, 2020).

The Mathematical Thinking working group of the PrimTED project, seeks to develop an alternative grounding experience of mathematical engagement in preservice primary mathematics education programmes. One that is deep, flexible and relates sense making in mathematics to sense making in the world. In addition, this working group seeks to develop exemplar resource materials that may be used to generate and develop such engagement in students, as well as assessment approaches that allow the identification, recording and evaluation of such engagement.

This paper discusses the developing mathematical knowledge of students as they progressed through a module designed to develop both mathematical thinking and fundamental mathematical content knowledge of students in a Primary Preservice Education programme specializing in the teaching grades R–3 (Foundation Phase). The module required students to engage in a varied array of tutorial and assessment questions that required the provision of elaborated responses in addition to the generation of answers to mathematical tasks and problems. Assessment results indicate a substantial improvement in students’ mathematical knowledge over the course of the module.

### Conceptualizing Mathematical Thinking for Primary Teachers

Mathematical thinking is a complex construct that is easy to talk about and difficult to define (Goos, 2018). In her review of research on promoting mathematical thinking over the period 2014–2018, Goos (2018) comments on the diversity of theoretical views on Mathematical Thinking. She makes the point that this may be productive in that it encourages different perspectives and research programmes, this also makes it difficult to synthesize findings and identify productive areas of research and development. In response to this, the working group chose to adopt an emergent, systemic, perspective on mathematical thinking, rather than an essentialist perspective. That is, instead of attempting to define mathematical thinking, a conceptual framework was be sought that identified different dynamical elements that together contributed to an emergent phenomenon that could be termed mathematical thinking.

A number of formulations and frameworks relating to mathematical thinking were consulted in the process. Including work on mathematical proficiency (Schoenfeld, 2007a; Kilpatrick et. al, 2001; Milgram, 2007), mathematical competencies (Niss, et. al, 2016), mathematical problem solving (Schoenfeld, 2007b), mathematical habits of mind (Cuoco, Goldenberg & Mark, 1996), the NCTM process framework (NCTM, 2000) and the PISA framework for the assessment of “cognitive mathematical competencies” (OECD, 2006). The development of an earlier version
of this framework has been presented in (Brown, McAuliffe & Lampen, 2018). The aim was not to define mathematical thinking, but rather to identify and describe process elements that would allow for the flexible analysis of the process of mathematical engagement. Identified process elements would thus need to be:

- Dynamical element of the process of mathematical engagement that could be related to some particular cognitive activity.
- Analytically distinguishable from other process elements, in relation to some aspect of the mathematical process.
- Serve some function that contributes to mathematical thinking in the process.

**Table 1: Mathematical Thinking Conceptual Framework Process Elements (V4)**

| Category 1: Playful engagement to develop, or search for, mathematical insight |
|---------------------------------|-----------------------------------------------|
| 1a. Act                         | Act or visualize for insight                  |
| 1b. Explore                     | Explore to relate                            |
| 1c. Connect                     | Connect to form networks                     |
| 1d. Clarify                     | Question to clarify                          |

<table>
<thead>
<tr>
<th>Category 2: Represent and use mathematics to deepen and refine engagement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a. Identify properties</td>
</tr>
<tr>
<td>2b. Describe and define</td>
</tr>
<tr>
<td>2c. Model</td>
</tr>
<tr>
<td>2d. Use representations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category 3: Structure mathematically to systematize understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a. Specialize</td>
</tr>
<tr>
<td>3b. Generalize</td>
</tr>
<tr>
<td>3c. Systematize</td>
</tr>
<tr>
<td>3d. Represent</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Category 4: Reason mathematically for justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>4a. Conjecture</td>
</tr>
<tr>
<td>4b. Justify or Refute</td>
</tr>
<tr>
<td>4c. Prove</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category 5: Reflect for action</th>
</tr>
</thead>
<tbody>
<tr>
<td>5a. Critique</td>
</tr>
<tr>
<td>5b. Attend to precision</td>
</tr>
<tr>
<td>5c. Reflect</td>
</tr>
</tbody>
</table>

Currently, the conceptual framework for mathematical thinking is organized into 5 different functional categories. Each containing 4 or 5 process elements:

- Category 1: Playful engagement to develop, or search for, mathematical insight
- Category 2: Represent and use mathematics to deepen and refine engagement
- Category 3: Structure mathematically to systematize understanding
- Category 4: Reason mathematically for justification
Category 5: Reflect for action

Table 1 shows the process elements currently included in the conceptual framework.

Primary school teachers are expected to display an adult understanding of children’s mathematics (Ma, 1999). Drawing on Tall’s (2008) three worlds of mathematics, mathematical meaning at the Primary Level could be seen as strongly linked to the conceptual-embodied and the proceptual-symbolic worlds. The conceptual-embodied world would emphasize the elements of action or visualization (1a), connecting (1c) to experience, identifying properties (2a) and attending to precision (5c). Practical experience in the embodied world also gives rise to a number of standard (canonical) models of mathematical objects and operations, which develop common connections between mathematics and the conceptual-embodied world. Identifying properties (2a) in situations that may be mathematized and quantifying them in a way that attends appropriately to precision (5c) allow for a flexible understanding of measurement – an important aspect of the process of mathematical modelling (Sriraman & Lesh, 2006).

The meaningful use of drawings and visualization (Duval, 2014; Presmeg, 2014) is also an important factor connecting mathematical conceptualization to the conceptual-embodied and proceptual-symbolic world. The developing mathematization of the proceptual-symbolic world would also draw extensively on the elements of representing (3d) and using representations (2d). Finally, systematizing (3c) and structuring, as well as reasoning, justification and refutation (4b) and critique (5a) are considered as fundamental components of mathematical sense-making at all levels of engagement (Kilpatrick et. al, 2001; Niss & Højgaard, 2019).

The module was designed to develop students’ experience of mathematics, covering a broad range of these elements and in this way challenge their prior, restricted experience of mathematics. In addition, the assessment of the module was also broadened to include many of these elements, and not focus merely on the production of formal, symbolic responses.

**Research Design**

The research reported in this paper, forms part of a design research project into resources and processes which may effectively incorporate mathematical thinking into the mathematics education of South African students studying to become primary school teachers. Ethical clearance was granted for this project on 8 Aug 2017, under ethical clearance number 17080801.

The research project uses the methodology of design research (Van den Akker, Gravemeijer, McKenney & Nieveen (Eds), 2006). The design research methodology follows a cyclical process similar to action research, although the focus is on the design of processes and artefacts, rather than social change. McKenney & Reeves (2012) identify the three main components of such a cycle (which they term a ‘micro phase’) as – 1) analysis and exploration; 2) design, construction, implementation and the collection of implementation data; and 3) evaluation, reflection and critique. The results of the reflection and critique then become the material for analysis and exploration leading to the design in the following cycle.
Four major facets were identified for design in the overall project. First, to design a conceptual framework for mathematical thinking that would be both analytically powerful and practically useful for course design and implementation in Primary school pre-service teacher education for mathematics. Second to design tasks and teaching activities that could be effectively used to deepen the mathematical experience of students in such pre-service education programmes. An important function of these activities was to provide points of common mathematical experience and for use to ‘foster delight in mathematics’ in primary pre-service teacher education programmes. Third, to design assessment processes that could serve to make mathematical thinking more visible and thus amenable to recording and assessment. Fourth, to design particular programmes in participating universities, that would build on the strengths of existing courses, to deepen and extend students’ engagement with, and learning of, mathematics in pre-service programmes in these universities. An important part of this design process is to share the strengths of existing programmes and allow staff members to strengthen their own programmes by building on the successes of others.

The overarching research objective for this project was thus: To research the design of a conceptual framework; tasks and teaching activities; assessment processes; and mathematics teaching programmes incorporating these, that would develop the mathematical thinking of students in Primary Preservice Teacher Education.

This paper reports findings from the third and fourth design facets for one particular module, which draws on the preliminary conceptual framework that was developed as the first facet of the research and is briefly presented above. This is a second year module, focusing on the mathematical development of students for the BEd (Foundation Phase) programme at a participating university. The paper first reports on the design of the tasks and teaching orientation for the module, paying particular emphasis on the assessment design. It then presents and analyses data generated through this assessment, over the full implementation of the module. The data was collected from a benchmark assessment (80 minutes, 53 marks) at the start of the year, a midyear test written in early June (2 hours, 99 marks) and the final examination written in late November (3 hours, 115 marks). It should be noted that all the work assessed in the benchmark test was included in the first half of the module and that the additional work for the second half of the year was included in the final assessment. These results provide some indication of the students’ developing mathematical proficiency over the duration of the module, as well as the possible influence of the module process on students developing mathematical knowledge – providing some insight into the effectiveness of this module for developing mathematical thinking.

**Module and Assessment Design**

The teaching of the module had a standard weekly structure. One double lecture (1 hour and 40 minutes) was taken to briefly introduce and develop a particular mathematical topic. This varied from quite standard topics such as place value, addition, multiplication, to flexible process-oriented topics such as identifying and measuring properties in a contextual situation, exploring patterns and sequences, and some engagement with mathematical modelling. Students were then provided with a tutorial sheet that set out mathematical tasks for them to do as homework.
Later in the week, students attended tutorial sessions (in groups of 25 or less) where a number of student tutors, as well as the lecturers for the course, were available for consultation and discussion. It was made clear to the students and constantly re-iterated that the assessment tasks would be similar to, but not precisely the same as, the tasks that they had been set in their tutorials for homework. The implication was that, if they had successfully completed their homework, they would be more than capable of passing the tests.

The restricted prior experience of many of the students and the time constraints of the course counted against the inclusion of many of the more open-ended elements of mathematical thinking identified in the conceptual framework. Students were given some exposure to these open-ended elements in the form of two periods, each devoted to a group modelling task (4 out of a total of 48 hours), and through guided experience of exploring and conjecturing, generalizing and specializing, as well as reflecting on process, during lecture periods. But there was no explicit focus on this in the assessment of the course. Rather than creativity and exploration, the orientation taken to mathematics in this course, was that mathematics is fundamentally about making sense and giving convincing reasons. Solutions were not seen as complete until reasons were given that showed that the solutions made sense.

The final elements selected for explicit inclusion in the course were those identified above. These are given in table 2.

**Table 2: Process elements selected as focal in the course**

| 1a. Act | Act or visualize for insight |
| 1c. Connect | Connect to form networks |
| 2a. Identify properties | Identify properties and invariants to view situations mathematically |
| 2d. Use representations | Use mathematical representations to achieve mathematical goals |
| 3c. Systematize | Systematize to build mathematical structure |
| 3d. Represent | Generate mathematical representations for written manipulation |
| 4b. Justify or Refute | Justify or refute when judging claims |
| 5a. Critique | Critique to select productions |
| 5b. Attend to precision | Attend to appropriate precision |

The provision of written responses was a particular emphasis in the course. Students were required to write down clearly how they made sense of the way mathematics related to their world, what processes they used to solve the mathematical tasks and questions they were set, reasons to justify their mathematical deductions and conclusions, as well as which approaches and strategies worked better for them and why. Such uses of writing in mathematics are advocated by Bicer, Capraro & Capraro (2013) in their study that shows the positive contribution that writing may make to developing children’s problem-solving skills, as well as by Pugalee (2005) who describes how writing may be used to develop children’s mathematical understanding, reasoning and problem solving. This emphasis draws on the idea of externalization and its importance for thinking, that is based on Vygotsky’s ideas of thinking and learning (Hardmann, 2008). According to Bazerman, (2012), externalization is what allows visibility of thinking to others, in that a person’s thinking only becomes apparent to others when it has become externalised and concretised through gestures, speech, or written (drawn) forms.
In the process of forming this externalization, the person’s thinking also developed and differentiated – that is, the externalization itself contributes to the persons’ thinking. This dual use of writing, to formulate and frame ideas and also to communicate with others for discussion and assessment formed an important component of the climate of the classroom.

It is emphasized by Burkhardt (2007) in his principle of “What you test is what you get”, that course assessment has a strong influence on students’ learning on the course. Leyendecker (2008) observes that this occurs because students put more effort into coursework that will prepare them directly for assessment and so result in better results. It was for this reason, that the close relation between tutorial work and assessment was kept and emphasized throughout the course. An important objective of the course was to expand students’ experience of mathematical thinking to include the varied elements discussed above. To maintain alignment, it was important to include this variation in the practical work and assessment of the course. Three different modes of responding were identified in the coursework, each of which could be directly elicited by appropriately formulated questions; compact, visual or elaborated responses. Assessment incorporated and balanced these modes of response.

Compact responses: This response mode focused on generating a solution to a mathematical question. For the purposes of assessment, the student was required to present only the generated solution. No additional elaboration was required. Some examples are:

- a calculation of 953 – 72,
- filling in the missing digits of a calculation (addition, subtraction or multiplication) in standard form with missing digits,
- working out and counting the factors when asked how many factors in a number such as 120,
- writing down the multiplication table and the division calculation for a division calculation such as 9975 ÷ 23,
- writing down and comparing area measurements of a region shown, using two different, drawn, measurement units,
- solving percentage or proportionality tasks, or
- determining digits in logic or addition puzzles (Sudoku or Kakuro).

Visual responses: This response mode involved the construction of visual configurations of given items, or the visualization of configurations and transformations that could be interpreted in a way that made sense of a mathematical statement. Assessment required the student to present a rough drawing, or diagram, that showed the configuration or transformation in a reasonable manner. Examples include:

- draw the construction of a given geometric figure using tangram or pentomino pieces,
- draw the covering used to determine the area measurements mentioned above,
- draw a standard model to illustrate a calculation, or a rational number, or
- draw a diagram to illustrate the appropriate aspects of a situated problem that could be mathematicised.
**Elaborated:** This response mode involved developing a reasonable argument to justify a deduction (conclusion) or a choice (opinion); or describing an embodied situation that could be interpreted to make sense of a mathematical statement. In each case, assessment required the provision of a written response that set out this argument or description. Many of the questions described above had a second part (often the same assessment value as the first) that required the students to justify their answer. Other examples included:

- justifying their preference for one of two solution strategies they provided for a calculation, based on a comparison of the strategies,
- ‘telling a story’ that described a grounding situation for a calculation or rational number, or
- Providing a reasoned response for a logical puzzle (such as a liar/truthteller puzzle).

Questions requiring compact responses were considered to be similar to student’s prior experience of mathematical assessment, as well as many standard questions used to assess mathematical competence. These questions were also differentiated according to the major mathematical topics covered in the course (and occurring in the Primary School curriculum). Major areas included additive thinking; multiplicative thinking; rational representations and proportional thinking; and measurement. Student results in each of these topic subdivisions were thus used to provide an indication of student competence in each topic, that would show some alignment with more standard measures of competence for those topics.

This paper will analyse students’ responses to assessment in each of these modes and each of the topic areas in the compact responses, throughout the duration of the course.

**Results**

It is important to note that this is not an experimental or quasi-experimental research project. For no control group was included in the design and also no attempt is made to judge the efficacy of the teaching intervention from the test results. Rather, the results of the tests are analysed with the aim of generating insight into the assumptions about prior mathematical learning used in the module design, as well as insight into the developing mathematical knowledge of the students over the duration of the module, and the possibilities for learning this design offer and the areas where further development is required.

**Table 3: Total marks and average percentages for each question type**

<table>
<thead>
<tr>
<th>Response mode</th>
<th>Benchmark Test</th>
<th>June Test</th>
<th>Final Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total marks</td>
<td>Average percentage</td>
<td>Total marks</td>
</tr>
<tr>
<td>Compact</td>
<td>26</td>
<td>33</td>
<td>43</td>
</tr>
<tr>
<td>Visual</td>
<td>6</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Elaborated</td>
<td>21</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>Compact add</td>
<td>11</td>
<td>56</td>
<td>9</td>
</tr>
</tbody>
</table>
The marks allocated for each category in each test, as well as the student means attained, are provided in table 3. It should be noted that only a single rational number question (4 marks) was asked in the benchmark test and that no rational number questions were asked in the June test because all the work on rational number in the course was included in the second half of the year. For this reason, rational number responses were not included in this analysis.

<table>
<thead>
<tr>
<th>Compact mult</th>
<th>6</th>
<th>14</th>
<th>25</th>
<th>45</th>
<th>15</th>
<th>74</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact measure</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>25</td>
<td>5</td>
<td>46</td>
</tr>
</tbody>
</table>

Figure 1: Student deciles for each of the response mode.

A more nuanced comparison of the student responses is provided by graphs showing student deciles in each of the categories. The graphs for the different response modes are shown in figure 1 and the graphs for the different mathematical topics in the compact mode are shown in figure 2.

In the initial benchmark, students attained an average of only 33% for compact responses and their average for visual and elaborated responses were even less (16% and 20% respectively). The frequency graphs show that the distribution of results for visual and elaborated responses was strongly skewed, both having modes in the 0–9 range. The subdivision of compact
responses into three content categories provides more insight into these responses. It can be seen that students only attained a passing average (56%) in the sub-category of additive operations, while the average response for both sub-categories of multiplicative operations and measurement were less than 20% (14% and 9% respectively). The distributions of responses for these sub-categories were also strongly skewed, with their modes occurring in the range 0–9.

![Frequency of Compact Responses (Additive)](image1)

![Frequency of Compact Responses (Multiplicative)](image2)

![Frequency of Compact Responses (Measure)](image3)

**Figure 2: Student deciles for different topics in the compact mode.**

Comparing these results over the period of the module, one can see a distinct improvement in all modes and all topic areas from the benchmark to the final exam. Results for the compact and elaborated response modes show a consistent increase from the benchmark, through the June assessment, to the final exam, while visual representations showed a great improvement in June and a decrease in the final examination. Students also demonstrated substantial and consistent improvement in each of the topic categories of the compact responses.

To validate these observations, T-tests were carried out on the results data for each of these categories in each of the tests. In each case, a T-test was evaluated to determine the probability that the measured distributions could have been drawn from the same population. Table 4 gives the results of these T-tests. The only cases in which the difference was not significant to the 99% confidence interval were the changes in additive thinking between the three assessments.
In the case of the change from the initial benchmark to the June Exam, the change was significant to the 95% confidence level. The average for the additive compact responses for the June exam was 68% indicating a reasonable degree of proficiency and this was slightly improved in the final exam – an improvement that could well have been a random fluctuation.

Table 4: T-tests: Probability of drawing the distributions from the same population

<table>
<thead>
<tr>
<th></th>
<th>Compact</th>
<th>Visual</th>
<th>Elaborated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bench / Test 2</strong></td>
<td>4.6851E-05</td>
<td>2.06252E-18</td>
<td>9.19E-05</td>
</tr>
<tr>
<td><strong>Bench / Exam</strong></td>
<td>3.1624E-12</td>
<td>6.90369E-13</td>
<td>2.1E-11</td>
</tr>
<tr>
<td><strong>Test 2 / Exam</strong></td>
<td>0.00042275</td>
<td>4.69065E-05</td>
<td>0.003934</td>
</tr>
</tbody>
</table>

**Compact: Different topic categories**

<table>
<thead>
<tr>
<th></th>
<th>Additive</th>
<th>Multiplicative</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bench / Test 2</strong></td>
<td>0.011536246</td>
<td>5.0325E-13</td>
<td>1.578E-05</td>
</tr>
<tr>
<td><strong>Bench / Exam</strong></td>
<td>0.000275097</td>
<td>3.7596E-29</td>
<td>1.837E-11</td>
</tr>
<tr>
<td><strong>Test 2 / Exam</strong></td>
<td>0.351363037</td>
<td>5.631E-12</td>
<td>8.092E-06</td>
</tr>
</tbody>
</table>

**Discussion**

The initial benchmark results support the findings by Carnoy & Chisholm (2008) and Venkat & Spaull (2015), that identify gaps in teachers’ mathematical content knowledge, including knowledge of some mathematical topics taught in Primary grades. These findings suggest that in pre-service student teachers, these gaps do not only occur in the minor topics, but may extend to the fundamental areas of multiplicative thinking and measurement. This finding also provided some support for the expectation that the mathematical knowledge of students entering the programme was poor.

The low benchmark results in both the visual and elaborated modes also supported the statement of Kilpatrick et al. (2001) that students’ prior experience of mathematics was often restricted to the rote learning of meaningless symbolic forms and constructions. The restricted nature of the prior mathematical experience of students entering Primary pre-service education, was a fundamental motivation for the development of the mathematical thinking conceptual framework (Brown, McAuliffe & Lampen, 2018) and for the design of the module, which set out to deliberately and explicitly challenge a restricted and overly formal view of mathematics. The benchmark results support these assumptions, indicating the fundamental need for such courses.

The analysis of the compact responses indicated that students’ mathematical content knowledge, as assessed in the more standard (compact) mode of mathematical assessment, had improved over the time period of the module. This lends further support to the proposition that a broader and more complex experience of learning mathematics leads also to improved performance in more standard assessments (Niss and Høgjaard, 2019; Schoenfeld, 2007b; van...
Two points need to be noted in relation to this. First, the nature of the research design (which was not experimental or quasi-experimental) does not allow for the verification of causal conclusions in this regard (Van den Akker, Gravemeijer, McKenney & Nieveen (Eds), 2006), however, the results do provide some indication that the module contributed to students’ positive mathematical development. Second, these results do not indicate whether or not this mathematical development was stable and will be retained over a more extended period of time. Further assessment is envisaged in the students’ final year, in order to investigate this question.

The majority of the students appear to have developed mastery of additive tasks over the course of this module. This development appeared to occur in the first half of the module, with only a small increase (more noticeable at the lower end) at the end of the year. Multiplicative tasks showed a steady increase throughout the year, with the majority of the students appearing to have mastered these tasks by the end of the module. Students showed a steady increase throughout the year in flexible and relational thinking about measurement, but it is also clear that a number of students had not mastered this topic by the end of the module. This is unfortunate because a flexible understanding of measurement provides the linking processes that allows one to generate quantitative models of situated phenomena in the world (Sriraman & Lesh, 2006).

The improvement in elaborated responses throughout the module was not as much as hoped for, indicating the need for effort to be expended on student’s writing and formulation of arguments. The visual responses show a great improvement in the first six months of the module, but the results are not as good in the line representations for rational numbers. This may have been due to the teaching of visual representations that occurred in the second half of the year. These included number line representations for additive and multiplicative operations, and number bar and number line representations for rational numbers. As discussed in Teppo & van den Heuvel-Panhuizen (2014), these are complex visual representations and require a great deal of time and effort for students to achieve mastery. It is clear from the results that more time and effort needs to be allocated to their learning throughout the module.

Conclusion

The assessment data from this year long implementation of the module, provides evidence that this design for teaching mathematics to preservice primary education students does indeed yield substantial gains, both to student mathematical content knowledge and to students’ broader engagement with mathematical thinking and meaning making. Students’ use of drawing and visualization for fundamental mathematical meaning making improved substantially over the first half of the module, but some of these gains were lost because students did not seem to successfully master the more complex, linear and rational number representations introduced in the second half of the year. The rapid early development suggests that it may be possible to introduce these more complex representations earlier in the module and so provide more opportunity for students to succeed in mastering them. Students use of argument and written meaning making did improve, but to a lesser extent, suggesting that more attention should be given to developing this aspect of mathematical thinking.
Students’ mathematical content knowledge relating to whole number operations, as indicated in the subdivisions of the compact response category showed the greatest improvement, with the final average of both the additive and multiplicative operations, ending at over 70%, improving from an initial benchmark assessment of 56% (additive) and 14% (multiplicative). Their measurement understanding also improved appreciably (from an average of 9% to 46%). But more work will need to be done with measurement and modelling, in order for these students to become fully proficient in using mathematics as a tool in the concrete-embodied world – a proficiency that is desired for those who teach our children mathematics in the Primary School.

The main principle for this module design and implementation was to broaden students’ mathematical experience in presentation, tutorial work and assessment. This was done by:

- including a number of different elements of mathematical thinking closely related to the conceptual-embodied and proceptual-symbolic worlds,
- emphasizing that mathematics was about making meaning and providing reasons, and
- requiring and relating responses in three different modalities

These positive results shown above suggest a preliminary hypothesis that these design and implementation principles may have enabled students to develop both a broader experience of mathematics and an improved competence in mathematical content knowledge.

Based on these results, it is recommended that:

- Further research on design, process and product, be carried out to refine, effectively formulate and appropriately test this hypothesis. This research will be continuing in the ongoing design research process.
- The implementation of these principles and practices be considered by those wishing to develop mathematics modules for preservice teacher education students with the aim of improving both their mathematical thinking and their competence in mathematical content knowledge.

References


Van der Berg, S. (2015). What the Annual National Assessments can tell us about learning deficits over the education system and the school career. *SAJCE, 5*(2), 28–43.

PRE-SERVICE TEACHERS’ LEVELS OF REFLECTION ON MATHEMATICS LESSONS: A REVIEW AND ADAPTATION OF FRAMEWORKS
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Rhodes University, South Africa

Abstract
Reflective practice is increasingly recognised as an important aspect for teacher professional development. Research on developing mathematics teachers’ reflective practice through analysis of video recorded lessons is on the rise. Several frameworks have been developed by a range of researchers across contexts to establish the levels of reflection teachers engage in while developing reflective practice. In this paper we provide a brief review of the rationale for the importance of developing teacher reflection in the context of mathematics teachers and then focus our review on comparing various analytic frameworks for analysing teacher reflections according to a range of levels. We argue, based on the findings of the first author’s doctoral research study that mathematics teachers’ reflection in the South African context requires some adaptation to these analytic frames. While this is primarily a review paper from which we propose an adapted analytic frame tailored to the South African context, we provide some exemplar pre-service teacher reflections to illustrate the nature of teacher reflections that led to the adaptation of existing frameworks.

Introduction
South Africa like many other countries has a standing record of poor student performance particularly in mathematics. Poor student performance in mathematics has been established in both national and international assessments. According to research this is partly a result of poor teaching in schools (Spaull, 2008). The majority of mathematics teachers in South Africa are said to lack adequate knowledge of content and pedagogy which result in poor teaching. Research suggests that teachers are not prepared well enough to meet the demands of the complex work of teaching hence education reforms are now focussing on the development of teacher knowledge. This paper is developed from the first author’s study that explored pre-service teachers’ (PSTs) reflective practice (RP) in the context of video-based lesson analysis with the aim of understanding the nature and levels of PSTs’ reflections as PSTs learn to reflect on practice. This was done to inform pre-service teacher education (PTE) practice and to contribute to knowledge of how to holistically develop PSTs particularly in mathematics education. In this paper we argue that while literature provides a range of models to evaluate the levels of reflection teachers engage in on the journey to becoming reflective practitioners, there is need to adapt the existing models for applicability in the South African PTE context. We seek to answer the questions: What models of teacher reflection are useful for analysing South African pre-service teachers’ reflective practice? How can these models be adapted as an analytic frame for South African pre-service teachers’ written reflections on practice? We start our discussion by describing the state of mathematics education in South Africa that necessitates reform of PTE and the inclusion of RP as a key component.
Mathematics education in South Africa

Both national and international reports on student performance in mathematics confirm a crisis of mathematics education in South Africa (Graven, 2014). Spaull & Kotzé (2015) state that poor learner performance in mathematics begins in the early years of schooling and that by the time learners reach Grade 3, only 16% will be performing at Grade 3 level. Mathematics performance continues to worsen as learners climb the ladder of education and the learning deficits developed at foundation phase then become difficult to redress in later years (Graven, Venkat, Westaway & Tshesane, 2013; Graven, 2016).

Research that seeks to understand the crisis points to poor teaching as one of the major contributing factors. Venkat and Spaull (2014) analysed the knowledge of Grade 6 teachers whose learners took part in the SACMEQ III evaluations. These teachers were given the same test as their learners and the analysis of their test results showed that 79% of them exhibited content knowledge competence below the Grade 6 and 7 levels. Furthermore, only 17% of those tested in the Eastern Cape Province (the province of our study) had adequate content knowledge to teach Grade 6. Wilmot (2017) in her inaugural lecture explained that poor teaching is linked to poor quality teacher education. She argued:

> There are many factors contributing to and sustaining a crisis in education in South Africa and globally, however, the findings of international and national research widely acknowledge that the single most important factor influencing the quality of education is the quality of teachers and that quality of teaching and learning cannot rise above the ceiling imposed by low teacher capacity; and the cause of poor teaching lies not with teachers but with the teacher education system that produced them. (Wilmot, 2017, p. 3)

Wilmot’s argument suggests the need for PTE to reform and find ways of equipping pre-service teachers (PSTs) with adequate knowledge and skills that will promote effective teaching. This paper contributes to understanding pre-service teachers’ reflective capabilities in order to inform ways in which teacher education can support pre-service mathematics teachers in becoming effective reflective practitioners (after Schön, 1987).

Research seeking to establish the reason behind the teachers’ weak mathematical knowledge for teaching (MKfT) (Ball, Thames & Phelps, 2008) concurrently suggests that teachers are not prepared well enough to efficiently handle the work of mathematics teaching. Adler (2005) claims that South African PTEs do not have sufficient knowledge on how to adequately prepare teachers. There are also knowledge gaps on what knowledge constitutes teacher knowledge (Adler, 2005). Watson and Barton (2011) argue “it is not just a question of what teachers know, but how they know it, how they are aware of it, how they use it and how they exemplify it” (p. 67). Thus, the problem of the teachers’ knowledge deficits links to inadequate teacher training.

According to Darling-Hammond, (2006), one other reason behind poor teaching is that novice teachers usually fail to make a connection between theories they learnt in their studies to their practice. This usually results in teachers reverting to the teaching styles they were exposed to during their lives at school as learners. There is therefore a need for PTE to prepare PSTs to reflect on their practice and establish how theory and practice come together. Developing PSTs’
Reflective practice (RP) has been noted as a key strategy for improvement as it has been widely found to significantly influence teaching. RP has also been credited for enabling teachers to “bridge the gap between the ‘high ground’ of theory and the ‘swampy lowlands’ of practice” (Meyer, 2020, p.1). Thus, RP enables exploration of theories and ability to apply them to experiences in a more structured way. The theories can either be formal from academic research, or informal, from one’s own personal ideas and beliefs. Exploration of these theories leads to finding solutions to problems.

**Understanding reflective practice and its role in teacher education**

Reflective practice has become a focus of interest and a powerful movement in teacher education. Dewey (1933) defined RP as an “active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the ground that supports it … [it] allows individuals to think critically and scientifically” (p. 9). RP enables teachers to pay critical attention to the practical values and theories which inform their everyday actions (Yaman, 2016). According to Schön (1987) examining practice reflectively leads to developmental insight and tacit knowledge. Boud, Keogh and Walker (1985) confirm that RP is an “important human activity in which people recapture their experience” (p. 19) and think about them in a way that influences their future actions. Finlay (2008) describes RP as learning through and from experience towards gaining new insights of self and practice. As a systematic review process, it allows teachers to make links from one experience to the next and make sure there is improved instruction that enables students to make maximum progress.

There are many reasons why RP is an essential skill for the practice of teaching. Darling-Hammond (2006) claims that teaching modern classrooms have become so complex that it is not possible to develop teacher knowledge that is kind of ‘one size fits all’. The demands of the modern work of teaching confirms Dewey’s (1933) argument that “it is impossible to become, and continue to be, an effective teacher without a personal commitment to reflective practice” (p. 9). As indicated earlier, the ability to reflect on practice has been found helpful in making teachers understand and meet the demands of teaching in the modern classrooms (Darling-Hammond, 2006; Yaman, 2016). In line with Ward and McCotter (2004), Yaman (2016) proposes that teachers should be trained to reflect both on the content of the subject they teach and how to apply particular teaching strategies.

**Developing pre-service teachers’ reflective practice**

The value of reflection as a medium to facilitate adapting to the dynamics of teaching and developing teacher knowledge (as discussed above) has repeatedly been confirmed in literature on teacher education (Ward and McCotter 2004; Russell, 2005). Darling-Hammond (2006) proposes developing RP in PSTs in order to provide PSTs with a comprehensive understanding of the complex dynamics of teaching and the factors that influence the classroom context. Russell (2005) suggests PSTs should be taught to reflect on practice to enable them to adapt. RP is necessary to assist PSTs in acquiring the knowledge that can validate their classroom decisions and actions and improve their teaching proficiency.
While RP is argued to be essential for teachers, research has established that it is not easy for PSTs to develop the skill and reflect meaningfully (Ward and McCotter 2004; Russel, 2005; Chikiwa, 2020). Ward and McCotter (2004) for example carried out an investigation to understand how PSTs reflect. They developed a rubric to illuminate the dimensions and qualities of PSTs’ reflections. Their research found that their participants were not engaging in meaningful reflections, suggesting the need to develop the PSTs’ RP explicitly. They commented:

We realized that we have often asked our students to reflect on field experiences without ever discussing the qualities of good reflection and often with disappointing results. Students do not automatically know what we mean by reflection; often they assume reflection is an introspective after-the-fact description of teaching. Reflection, meant to make teaching and learning understandable and open, has itself been an invisible process to many of our preservice teachers (p. 255).

Thus, Ward and McCotter (2004) argue for the need for explicit development of RP in PTE. This requires understanding the nature of PSTs’ RP and how it might develop through PTE. A wide range of research has been carried out to contribute to the knowledge on how RP develops both in in-service and PSTs. Different models of levels of reflection have been proposed in these studies. We review the key studies that informed the research study on the nature of reflections PSTs engage as they analyse video-recorded lessons in one Eastern Cape University. Before doing this however, we briefly explain the methodology of the broader doctoral study as it is the data from this study, and analysis thereof, that led to our adaptations to these existing models.

**Methodology**

The study on which this paper is based is a qualitative case study with 19 PSTs in their third year of bachelor of education degree at a University in the Eastern Cape. As part of the mathematics method course, the PSTs went through three sessions of watching and analysing selected foundation phase mathematics lessons with their lecturer. The intention of the lecturer was to develop their MKfT and RP. The lecturer employed the Six Lens Framework developed by Karsenty, Arcavi and Nurick (2015) to guide the PSTs’ reflections. Since our interest was on the nature of reflections PSTs engaged as they analysed video-recorded lessons, we analysed the written reflections of the 19 PSTs who volunteered to take part in the study to establish their levels of reflection on each of the three lecture sessions. These reflections were transcribed and analysed using content analysis. A thorough literature search was conducted to find the most suitable model for analysis. However, while we found several models to be relevant each did not fully suit the needs of our data. We therefore adapted and combined elements from two models into one that was tailored to the needs of our research. The details of this adaptation and combination are discussed in the next section.

**Adapting models for analysing South African pre-service teachers’ levels of reflection**

As mentioned earlier, literature provides a range of models for analysing levels of reflection. Lee (2005) provides a list of such models. Most scholars working in TE identify three levels of
reflection, hierarchically progressing from simple descriptions of classroom events, often with a main focus on technical aspects of teaching, such as classroom management and content delivery; to thoughts about the what, how and why of teaching, suggesting alternative viewpoints and raising new questions that need to be resolved (Van Manen, 1977; Lee, 2005; Cavanagh & Prescott, 2009; Muir & Beswick, 2007). According to Leijen, Valtma, Leijen and Pedaste (2012) categorising reflective thinking began with Habermas in 1972 who proposed three different kinds of knowledge-constitutive interests: technical, practical and emancipatory, with each knowledge interest initiating a certain ‘way of knowing’. Leijen et al. (2012) claim that Van Manen (1977) drew from these kinds of knowledge and developed a hierarchical model with three levels of reflection: technical, practical and critical reflection.

Van Manen (1977) studied PSTs’ reflective thinking with a focus on the moral and social implications of teaching and developed a framework to describe PSTs’ RP development. After analysing PSTs’ reflections based on the orientations of social science and their cognitive interests, he distinguished three hierarchical stages of RP. These were: (1) technical rationality—where PSTs’ reflections simply attend to strategies that work or fail in classroom settings; (2) practical action, where the PSTs focus on the learning experiences and start to recognise teaching as problematic; and (3) critical reflection, in which the participants deliberate on the moral and social implications of classroom practices. Scholars have subsequently developed various models of RP for both in-service teachers and PSTs from Van Manen’s (1977). Due to space limitations we focus here on only those that were considered most suitable and whose work is combined into the adapted framework.

Lee (2005) carried out a study with PSTs registered to train as secondary school mathematics teachers. In her investigation of the content and depth of PSTs’ reflective thinking, she analysed their reflections on their own experience teaching during teaching practice. Influenced by Van Manen, Lee (2005) concluded that the PSTs’ RP goes through three hierarchical stages. However, Lee (2005) identified the first stage of her model as recall. According to Lee (2005), at this stage the PST “describes what they experienced, interprets the situation based on recalling their experiences without looking for alternative explanations, and attempts to imitate ways that they have observed or were taught” (p. 703). Lee’s (2005) second stage rationalisation is when PSTs provide a rationale for the identified classroom events which they use to develop general principles for future instruction. Lee (2005) identified her third and final stage as reflectivity, which occurs when the PSTs start to analyse experiences from various perspectives and think of alternatives for future action. This stage is identified by other scholars as the critical reflection level (e.g. Robinson & Kelley, 2007; Muir & Beswick, 2007). Lee (2005) claims that at this level “one approaches their experiences with the intention of changing/improving in the future, [and] analyses their experiences from various perspectives” (p. 703). On the same topic, Robinson and Kelley (2007) observe that reflectivity “considers entire context; discourse with self and explores possible reasons for actions. Steps out of self and observes from a distance” (p. 36).

Muir and Beswick (2007) investigated how a relatively experienced teacher reflected on his practice. To analyse their data, they developed a model with “three increasingly sophisticated
levels of reflection” (Muir & Beswick, 2007, p. 78). Like Van Manen (1977) and Lee (2005), Muir and Beswick (2007) found that RP develops in three hierarchical phases: technical description, (probably from Van Manen’s (1977) first level of technical rationality) where PSTs give general accounts of classroom experience, often focusing on the technical aspects of teaching. Both Muir and Beswick (2007) and Van Manen (1977) display interest in the technicalities of teaching. Lee (2005) does not mention the technical aspect of reflections, most probably because she was dealing with PSTs who were not yet familiar with the technical vocabulary of teaching. Muir and Beswick’s (2007) level 2 is deliberate reflection, a level at which critical incidents are identified and explained. What we found key in this stage is that, both for Lee (2005) and Muir and Beswick (2007), there is provision of an explanation for the identified classroom incident. Their level 3 is critical reflection, where the teacher moves beyond identifying and explaining critical incidents to considering and contemplating alternative actions. Table 2 below summarises and compares the levels of RP and key indicators for each of these models.

Table 1: Comparison of Lee’s (2005) and Muir and Beswick’s (2007) models of levels of reflection

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>MODEL OF REFLECTION</th>
<th>KEY INDICATOR for each level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recall level</td>
<td>Description of classroom incidents without giving explanation</td>
</tr>
<tr>
<td></td>
<td>PSTs describe classroom events recalling their learning experiences without looking for explanations</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rationalisation</td>
<td>Deliberate reflections</td>
</tr>
<tr>
<td></td>
<td>PSTs look for relationships between pieces of their experiences, interpret the situation with rationales, search for “why it was,” and generalise their experiences or come up with guiding principles</td>
<td>Providing Explanation behind identified classroom experiences</td>
</tr>
<tr>
<td>3</td>
<td>Reflectivity</td>
<td>Critical reflections</td>
</tr>
<tr>
<td></td>
<td>PSTs approach their experiences with the intention of changing/improving in the future, analyse their experiences from various perspectives, and suggest alternatives</td>
<td>Analysis of event from various perspectives and Suggestion of alternatives for future instruction</td>
</tr>
</tbody>
</table>

As mentioned above we found these two models to be very helpful but not fully suited for the data emerging from our study. We therefore adapted and merged Lee’s (2005) and Muir and Beswick’s (2007) models of levels of reflection adopting the key indicators for each of their levels of reflection for identification of the levels of our model as shown in Table 2 below. We explain our rationale for adaptation and our delineation of levels and choice of level descriptors and indicators below.
As seen in Table 1, above, both Lee (2005) and Muir and Beswick (2007) associate the first level with *description* of classroom occurrences. This level worked well to categorise the majority of PST’s written reflections. We therefore named level 1 of our model *description*. We decided not to adopt the term ‘technical’ because our PSTs’ descriptions were in general not as technical as Muir and Beswick’s examples, which came from an experienced teacher. As indicated earlier, we worked with third year PSTs who did not have much classroom experience and therefore tended not to use technical language when noting classroom experiences. They wrote such reflections as “A learner has to raise hand to talk” (Lethu, S1), or “the teacher dealt with subtraction as well as addition” (Alice, S1).

As shown in Table 1 above, the key indicator for level 2 consists of rationale/explanations provided for the classroom incidents identified in both Lee’s (2005) and Muir and Beswick’s (2007) level 1 of reflection models. This level had the clear indicator of providing an explanation of an event and so we adopted this as level 2 and kept the name *explanation* for our model. Thus, level 2 of our PSTs reflections consisted of explanation of why a classroom event occurred, such as “She [the teacher] used an actual umbrella so that the learners can visually see the concept” (Alice, S1). Thus, the PSTs’ described events were followed by basic explanations we considered to be level 2 reflections.

Both Lee’s (2005) and Muir and Beswick’s (2007) third levels are characterised by analysis and the provision of suggestions. We however found that our participants tended to provide occasional suggestions but without any evidence of these being linked to analysis, which made us reluctant to classify such suggestions as evidence of critical reflection. For example, Dumie wrote “I would have used the mental math strategy for teaching because it is very useful to develop number sense” (S3). Dumie does not motivate why this strategy would be more useful. We therefore positioned ‘suggestions’ at a level of reflection between Lee’s (2005) and Muir and Beswick’s (2007) levels 2 and 3. We thus created and named our third level *suggestion*.

The aforementioned frameworks’ level 3 then became our level 4 which we adopted Lee’s (2005) name of *reflectivity*. We preferred the name reflectivity to Muir and Beswick’s (2007) naming of level 3 as critical reflection because this allowed for analysis from multiple perspectives and considering alternatives without the connotation of being ‘critical’ of an event. None of our PSTs reflected at this level during the three sessions the PSTs had with their lecturer. The only reflection in the whole study that showed reflectivity was written by one PST while reflecting on the video recording of his own teaching after three small group intense facilitator guided sessions. Bonga wrote “I shouldn’t have put together addition and subtraction because learners were not really focused and couldn’t understand the subtraction part, they needed it to be done separately. These two [algorithms] are already complicated for Grade 1 to use on 2-digit numbers and putting them together was not a good idea because I ended up spending more time on addition and very less time on subtraction. Many learners seemed to get confused when I wanted them to subtract. That was not good for the learners. They didn’t learn much from it. I should have stuck with only one”.

Our adopted and adapted model therefore consists of four hierarchical levels of reflection: Description, Explanation, Suggestion, and Reflectivity, and we named it the Four Levels of
Reflection Model (FLRM). Table 2 below shows the FLRM we developed by merging two models of reflection as discussed above. The examples cited in the model were taken from the PSTs’ written reflections.

Table 2: The four levels of reflection we developed after merging two models (adopted from Chikiwa, 2020, p.99)

<table>
<thead>
<tr>
<th>LEVEL OF REFLECTION</th>
<th>DESCRIPTION OF EACH LEVEL</th>
<th>KEY INDICATORS</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 Description</td>
<td>PSTs describe classroom incidents without providing an explanation for them</td>
<td>Description of classroom occurrences with no explanations</td>
<td>The teacher encouraged children to respond in full sentences</td>
</tr>
<tr>
<td>Level 2 Explanation</td>
<td>PSTs identify the classroom occurrences and provide explanations for them</td>
<td>so that; because; so as to; in order to; which resulted; which made; as a result of; to; this was done to</td>
<td>This was to encourage children to answer questions in full in order to build their communication skills</td>
</tr>
<tr>
<td>Level 3 Suggestion</td>
<td>PSTs go beyond identifying and providing explanation for classroom occurrences to analysing the classroom experiences and suggesting alternatives</td>
<td>could have would have should could next time</td>
<td>Other strategies such as using a spider diagram could have made her lesson more interesting and easier.</td>
</tr>
<tr>
<td>Level 4 Reflectivity</td>
<td>PSTs engage dialogically with the classroom event, analysing it from different perspectives</td>
<td>Analysis from various perspectives and suggestion to improve instruction</td>
<td>See example written by Bonga, above</td>
</tr>
</tbody>
</table>

In order to appropriately analyse our data we had to develop some sub categories for each of the four levels of our model as detected by the data. We chunked the PSTs’ written reflections (using rules established for this purpose) so that each written idea could be coded. As we coded the data we found that the reflections fell into two categories: either general or mathematical. General reflections were either generally pedagogic, applying to the teaching and learning of any subject (such as “The teacher asked a lot of questions” [Charity, S1]). Mathematical reflections on the other hand were those that related specifically to the teaching and learning of mathematics. These were identified through the explicit mention of mathematical concepts, terms, numbers, symbols or ideas, e.g. “She [the teacher] also takes an opportunity to introduce number names and digits” (Liz, S1). We therefore had to develop sub codes that met the needs of our data for all the levels in the FLRM resulting in:

- level 1: general descriptions (GD) and mathematical descriptions (MD);
- level 2: general explanations (GE) and mathematical explanations (ME);
- level 3: general suggestions (GS) and mathematical suggestions (MS); and
These subcategories worked well for the reflections from session 1 (S1), however as we coded session 2 (S2) and session 3 (S3) we found the need to further develop our categories. We had to distinguish the reflections that were followed by explanations and those that were simple (followed by no explanation). We employed a superscript arrow with an ‘E’ (→E) at the end of each of the descriptions and suggestions that were followed by explanations. Those without superscripts were considered simple descriptions/suggestions. For example, “The teacher uses open-ended questions MD→E to promote the meta-mathematical idea she had” (Marylyn, S2). We further found that the initial labelling of explanations as simple or analytic did not capture the two main types of explanation we noted from data. There were explanations we coded as simple because they had one explanatory idea linked to a description/suggestion and those we identified as expanded explanations, because they had two or more connected ideas jointly explaining a description. These were therefore coded together with a superscript number indicating the number of explanatory ideas. If the explanation was expanded with one idea, the code was given a superscript ‘E’ but no number. For example, “She used the number line to find to the nearest 10 [MD→E] because using a number line makes it easy to find the nearest 10” [ME] (Tiny S3). However, if the explanation was expanded with more than one idea then a superscript ‘E’ was followed by a ‘e’ signifying the number of ideas in the explanation. For example, “The chorus answering may cause a problem GD→E because the children may parrot each other. This means that a student may not understand, and the teacher may not know” GE® (Mickey S3). If the explanation was expanded, a superscript e was added to the code as shown in the above example (GE®). Thus, the absence of superscript indicated that this was a simple explanation, hence the superscript “e” indicated that the explanation was expanded with one idea or more. Table 3, below, show the codes that we finally used to code all our data.

Table 3 The summary of codes used in coding all the data (Chikiwa, 2020, p. 110)

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>EXPLANATION</th>
<th>SUGGESTION</th>
<th>REFLECTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Description</td>
<td>(Simple) General Explanation</td>
<td>General Suggestion</td>
<td>General Reflectivity</td>
</tr>
<tr>
<td>General Description Followed by explanation</td>
<td>Expanded General Explanation</td>
<td>General Suggestion Followed by explanation</td>
<td>Mathematical Reflectivity</td>
</tr>
<tr>
<td>Mathematical Description</td>
<td>(Simple) Mathematical Explanation</td>
<td>Mathematical Suggestion</td>
<td></td>
</tr>
<tr>
<td>Mathematical Description Followed by explanation</td>
<td>Expanded Mathematical Explanation</td>
<td>Mathematical Suggestion Followed By explanation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
We noted from literature that Cavanagh and Prescott (2009) like us, also worked with PSTs and merged Lee’s (2005) and Muir and Beswick’s (2007) levels of reflection models to develop a tool for analysing the reports PSTs wrote about their teaching practice (TP) experiences. In merging Lee’s (2005) and Muir and Beswick’s (2007) models, they developed a hierarchical model with again three levels of reflection. Level 1: *descriptive recall* where participants provided “general descriptions of classroom practice, evaluating the success or failure of actions, focusing on the technical aspects of teaching e.g., ‘I ran out of material at the end of the lesson’” (p. 275). The term ‘descriptive recall’ echoes the terminology of Lee’s (2005) and Muir and Beswick’s (2007) level 1: ‘recall’ and ‘technical description’ respectively. Cavanagh and Prescott’s (2009) level 2 was named *practical rationalisation*, where PSTs could identify classroom incidents and provide explanations for them. The term ‘rationalisation’ is seen in level 2 of Lee’s (2005) model, where rationale is the key indicator. Cavanagh and Prescott (2009) call this level ‘practical rationalisation’ because PSTs give “accounts of critical incidents; explaining the actions; searching for causes…” (p. 274). Their level 3 is *critical reflection*, like that of Muir and Beswick (2007). Here the PSTs provide analysis of classroom experiences from various perspectives and offer alternatives. This level is equivalent to our fourth level of reflectivity. We did not adopt Cavanagh and Prescott’s (2009) model for the reason we gave above that we needed a level between explanation and the analytic reflectivity level because our PSTs were giving suggestions that did not qualify to be categorised at an analytic or other or multiple perspectives level.

As indicated earlier, the 19 PSTs in our study did not write reflections that were at level 4 (See Chikiwa, 2020). The only level 4 reflection emerged in a follow up phase of the study that engaged a smaller sample of four PSTs who were taken through additional facilitator guided reflection sessions. This points to the critical importance of explicitly developing reflective practice with careful mediation including having the mediator model what higher analytic reflectivity looks like and asking probing questions that push PSTs towards deeper (and higher levels) of reflection.

**Concluding remarks**

Drawing from our research findings we argue that while literature provides a range of useful models of reflection, we found the need to adapt these levels by i) creating a range of sub levels within the lower levels of reflection and ii) creating an additional level of suggestion between the levels of explanation and critical reflection. The reason for the former is that the vast majority of our data was categorised at the first two levels meaning that if we wanted to get a better sense of the nature of the reflections, we would need to unpack these levels in more detail. The latter emerged from the way in which the ‘suggestions’ found in our data were often at a simple level where one could not infer that the suggestion emerged from analysis or critical reflection. Our adapted model thus shared many features of the three levels of existing frameworks (Lee, 2005; Muir & Beswick, 2007; Cavanagh & Prescott, 2009) but with the aforementioned adaptations. This model worked well as an analytic frame for the data (Chikiwa, 2020).
Acknowledgement

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References


ALIGNMENT BETWEEN MATHEMATICS TEACHER EDUCATORS’ UNDERSTANDING OF FORMATIVE ASSESSMENT AND GHANA’S POLICY ON ASSESSMENT
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University of KwaZulu Natal

Abstract
This paper looks into the extent of alignment between mathematics teacher educators’ understanding of formative assessment and policy on assessment in the context of Ghana. This qualitative, interpretive study was framed using the social-cultural theory of learning and was located at three teacher colleges in Ghana. Data generated from semi-structured interviews and textual materials (students’ assessment scripts) were analysed using thematic coding and interpretive strategies. Four main themes with their corresponding categories emerged during the data analysis. The alignment of four different aspects of formative assessment captured in Ghana’s policy documents was compared with mathematics teacher educators’ understanding of formative assessment based on the themes generated during data analysis. The study established existence of a close alignment between policy and teacher educators’ understanding in three areas: definition of formative assessment, the functional role of formative assessment, and formative assessment strategies. There was one misalignment – nature of feedback. The researchers therefore recommend a teacher support programme for educators on how to give feedback comments that move learning forward, in line with Ghana’s policy on assessment.

Introduction
Without assessment, teachers and students would have no way of knowing whether or not learning is taking place (Broadfoot, 2012). In other words, assessment is a way of finding out if learning has taken place, a process which requires teachers’ understanding and skills in order to ensure effective implementation. Moss (2013) posits that assessment is “undeniably one of the teacher’s most complex and important tasks” (p. 235). The pivotal role of assessment in education has led educators, researchers, and policy makers in search of classroom practices that support students’ learning and achievement (Sato, Wei & Darling-Hammond, 2008). Formative assessment (FA) has been identified as having the potential of improving students’ learning outcomes (Black & Wiliam, 1998; McMillan, 2007). FA is a process of generating information about students’ learning, and the instructional strategy might be modified where necessary based on the evidence gathered (Cauley & McMillan, 2010).

After interrogating different forms of assessment, Black and Wiliam (1998) aver that assessment forms part of teachers’ classroom practices and when used effectively has the potential of improving learning as well as students’ achievement. It is therefore important for teachers to have the skills and understanding of assessment techniques, and to use assessment data to account for the context within which learning occurs (Rao & Sun, 2010).
Teacher educators are responsible for training teachers, equipping them with skills and knowledge to become effective practitioners in the school setting. Therefore, the teacher educator’s knowledge of assessment issues is not only vital for planning and designing teaching and learning activities, but also for addressing the learning needs of students. Arrafi and Sumarni (2018), in their study of teacher’s FA literacy and practices, found that teachers’ understanding of FA is inadequate. Teachers’ understanding about FA may be insufficient, which prevents them from implementing FA in the classroom (Bennet, 2011). Similarly, Watson (2006) noted that teachers have trouble in using FA effectively to guide teaching.

In support of Bennet (2011) and Watson’s (2006) positioning, Husain (2013) argued that teachers’ lack of knowledge of FA and the use of FA techniques might hinder the effective implementation of FA in the classroom. As noted in the above literature there is a plethora of research on in-service teachers’ knowledge of FA. However, the focus of these studies has been at school level, while there is a dearth of research on teacher educators’ knowledge and practice of FA in mathematics modules. In-service teachers are the product of teacher colleges, and when they become practitioners, they mostly implement the skills and knowledge acquired while they were pre-service teachers. It is therefore imperative to explore teacher educators’ knowledge and practices of FA.

In Ghana education policies support the inclusion of FA; however, when it comes to teachers’ knowledge of FA and how this aligns with policy, it appears that not many studies have been done. Amoako, Asamoah and Bortey (2019) investigated knowledge of FA among senior high school mathematics teachers in Ghana, and found that they have low knowledge in FA practices. In a similar manner, Oduro-Okyireh et al. (2015) established in their study on senior high school teachers’ practices of FA that teachers lacked a conception of FA and its sub-concepts.

It is evident that none of these studies explored how teachers’ conceptions align with acceptable standards of FA as enshrined in the policy documents on assessment in the context of Ghana. This paper aims at closing the gap by exploring teacher educators’ understanding of FA and how this aligns with the policy on FA in the context of Ghana. The paper is guided by the critical question: *What is the alignment between teacher educators’ conception of and formative assessment policy in the context of Ghana?*

**Formative assessment policy in the context of Ghana**

Bennett (2011) reported that the effectiveness of innovation could be meaningfully documented if innovation is clearly defined. This means that definition is very important for conceptual understanding, and aids educators to know what needs to be implemented. Ghana’s National Council of Curriculum and Assessment (NaCCA) (2018, p. 34) says that FA “provides feedback and information during a teaching and learning process, while teaching is taking place, and while learning is occurring”. The NaCCA explained that FA measures students’ progress as well as evaluating the teachers’ own progress in delivering content in a manner that ensures that learning is taking place. The purpose of FA in Ghana’s schools, according to the NaCCA, is to improve learning and shape and direct the teaching-learning process, which is consistent with the literature (Black & Wiliam, 1998; Cauley & McMillan, 2010).
FA tools and techniques come in different forms, depending on the topic. In Ghana, the NaCCA (2018) listed and recommended to teachers FA tools like: 1) observations during in-class activities, 2) homework exercises as a review of class discussions and signal for future teaching and learning activities, 3) question and answer sessions, both formal (planned) and informal (spontaneous), and 4) reflection journals (NaCCA, 2018, p. 34). It is expected that teachers make use of these FA strategies during classroom instruction. This means that there is a need for clear understanding of FA by teachers and teacher educators, in order to ensure effective implementation of these strategies in the classroom.

**Theoretical considerations**

According to Merriam (2009), qualitative researchers want to understand how their participants make sense of their experiences in a social and cultural context. The standpoint of Merriam serves as a support for the aim of this study and the research question. FA is a collaborative activity between students and their teacher in support of learning, and therefore the theoretical framework of FA should be understood within the social-cultural context (Black & Wiliam, 2009; Pryor & Crossouard, 2008). The theoretical framework of this study is therefore informed by the social-cultural theory of learning, as explained below.

**Social-cultural theory of learning**

According to Bryman (2016), sociocultural theories are based on a social constructivist paradigm which views knowledge development as a social phenomenon that occurs through sharing and interaction by individuals. Similarly, Wang, Bruce and Hughes (2011) assert that in the context of a sociocultural perspective of learning, human cognition is developed through social activities as the individual interacts with other people, objects, and events. From the perspective of the sociocultural view, FA emphasises social interaction between the teacher and his students in order to accomplish the assessment task.

The concept of the zone of proximal development is the most widely applied sociocultural concept in the design of learning experiences (Polly et al., 2017). Through FA, learning is shaped during instruction. The help or support offered by FA practices with the intention of improving learning is called ‘scaffolding’ within the context of the sociocultural perspective. According to FA researchers, FA practices are a process of scaffolding (Brookhart, Moss & Long, 2010; Pryor & Crossouard, 2008). FA has been equated to the scaffolding by Torrance and Pryor (1998), who argued that FA is more a form of teaching than assessment.

FA is being used almost interchangeably to mean similar practices and procedures as the term assessment for learning (AFL) (Oz, 2014). In other words, AFL is considered a contemporary form of FA. According to the Assessment Reform Group (2002, p. 2), AFL is referred to as “the process of selecting and interpreting evidence for use by learners and their teachers to decide where the learners are in their learning, where they need to go and how best to get there”. AFL integrates assessment into instruction as an ongoing process where teachers use assessment information to make adjustments in their instructional endeavours and resources (OZ, 2014). According to relevant literature, the most significant difference between FA and AFL is that FA informs teachers about students’ learning, while AFL informs students about
their own learning (Stiggins, 2005; Wiliam, 2011). AFL puts emphasis on the day-to-day progress of learning as students climb the curriculum scaffolding leading up to state standards (Oz, 2014; Stiggins, 2005), and is grounded on the principles of FA (Stiggins, 2005). For the purposes of this paper, the term formative assessment (FA) is used synonymously with assessment for learning (AFL).

**Materials and methods**

As indicated in the abstract, the study was located within the interpretive paradigm as it seeks to understand the phenomena from the perspective of the participants and situated within a mathematics classroom in three teacher colleges of education in Ghana. Realising that the study focuses on the alignment of participants’ understanding and the four FA issues raised in the policy documents, an exploratory research design was followed. The study also adopted a qualitative case study approach owing to its relevance to the research. The hallmark of a good qualitative case study is that it dispenses an in-depth understanding of the case, and achieving this requires collection and integration of different research strategies, ranging from interviews to observations, textual materials, and audiovisual materials (Creswell & Poth, 2016).

**Participants**

Six mathematics teacher educators from three teacher colleges were purposively selected to take part in the study. The participants were named and identified using the pseudonyms Sekyi, Emily, Anani, Peprah, Wilson and Fordjour. The criteria for participation were that the individual teacher educator must have taught at teacher college level for more than a year through the recommendation of the Head of Department. In each teacher college, two teacher educators who met the criteria were invited to participate in the study. All of the participants signed a consent form to participate in the study, and they were assured of anonymity.

**Instruments**

Qualitative data include documents and participants’ responses from interviews, and analyses thereof. In this paper we report on findings from interviews with teacher educators and analysis of students’ assessment scripts (textual material). Interviews were conducted with the six participants. Qualitative interviewing offers researchers the opportunity to explore the opinions of individuals and how they give meaning to or interpret their experiences (Low, 2013).

**Data analysis**

To analyse teacher educators’ understanding of FA a system of themes describing aspects of FA from the literature was developed followed by content analysis of teacher educators’ responses. The analysis was informed by Rowntree’s (2015) five dimensions of assessment. Rowntree argued that teachers’ knowledge of assessment is determined by their understanding of the following five assessment dimensions: 1) purpose or expected outcome (why assess?), 2) content and/or skill (what to assess?), 3) methods or means (how to assess?), 4) interpretation, explanation and/or application (how to interpret?), and 5) response, communication and/or intervention (how to respond?). These dimensions were adapted and narrowed to FA and compared with the themes that emanated from data after the content analysis. Four major
themes, each with its unique category (see Table 1) were developed, providing the basis for exploring teacher educators’ understanding of FA.

### Table 1: Themes and related categories developed by content analysis of participant interviews

<table>
<thead>
<tr>
<th>Theme 1: Mathematics teacher educators’ definition of FA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1</strong></td>
</tr>
<tr>
<td>FA is an integral part of teaching</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theme 2: Understanding FA purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1</strong></td>
</tr>
<tr>
<td>FA is a tool that informs teaching and learning</td>
</tr>
<tr>
<td><strong>Category 2</strong></td>
</tr>
<tr>
<td>FA is for evaluating achievement of learning outcomes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theme 3: FA strategies that teacher educators exhibited knowledge of</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Category 1</strong></td>
</tr>
<tr>
<td>Assessment methods are formal and informal</td>
</tr>
</tbody>
</table>

| Theme 4: Mathematics teacher educators’ feedback practices |

### Results and Discussion

This section presents the findings of the research in response to the research question, and has been organised into two parts. The first part presents results and discussion of mathematics teacher educators’ understanding of FA, while the second matches teacher educators’ understanding with issues raised in policy documents on FA, to ascertain alignment/nonalignment between participants’ understanding and the FA policy of Ghana.

**Teacher educators’ understanding of formative assessment**

The themes that emerged from the data are discussed in this section.

**Formative assessment is an integral part of teaching**

The study established that teacher educators consider FA as an ongoing process which forms part of teachers’ pedagogical activities. The notion that FA forms an integral part of teaching is exemplified in the following interview transcripts:

**Anani:** Formative assessment is the day-to-day assessment of people's achievement. Class assignments, quizzes, group work, projects that one is doing on a daily basis.

**Emily:** … formative assessment is continuous, it is not a one short, so it can be done before your lesson to see where they are, it can be done in between your presentation to see if they follow what you are teaching, or it can be done ...

In a similar manner, Peprah, another participating teacher educator, averred that:

**Peprah:** … is the assessment that you conduct as part of the progress of the teaching and learning …

The preceding transcript excerpts indicate that teacher educators consider assessment as formative when it forms part of ongoing instruction. This finding resonates with that of Oz (2014) that the extant form of FA integrates assessment into instruction as an ongoing
process, where teachers employ assessment data for instructional modification. The finding is also supported by the claim advanced by Brink (2017) that FA is a continuing process and an integral component of the teaching and learning process (Thomas et al., 2011).

A key characteristic of FA that emanated from the teacher educators’ responses was the time of occurrence. Their responses portray that FA should be done in real time, and mentioned the three stages of instruction: before teaching, during teaching, and after teaching.

Trumbull and Lash (2013) conceived that FA is determined by its purpose of assisting and shaping students’ learning during the learning process. Interview data revealed two conceptions of the formative role of assessment by teacher educators, as outlined below.

**Formative assessment informs teaching and learning**

Findings of the study indicate that four (Sekyi, Wilson, Fordjour and Peprah) of the teacher educators conceived FA as a process that supports teaching and learning. For instance, in his response Sekyi demystifies the role of assessment data to the teacher. He explained that FA allows teachers to appraise their teaching and the method of instruction:

*Seki*: … to measure whether whatever you are teaching is going on well or also the method that you are applying in teaching them is also going on well.

Likewise, Peprah said: I assess to find out their progress and understanding of the concept taught and to determine whether I am making progress in my teaching.

According to these teacher educators, FA should be employed by teachers and students mainly to assist in teaching and learning. Their conception implies that FA provides feedback relative to students’ learning and teachers’ instruction.

**Formative assessment is for evaluating achievement of learning outcomes**

The result of the interviews showed that two teacher educators in this study observed that assessment is about tracking and organising students’ achievement against learning outcomes. One of these teacher educators, Anani, stated as follows:

With assessment, we are trying to set a value on students' performance to determine their actual achievement. So, we [I] assess to be able to know whether they have achieved what they have been taught, assessment is done for grading purpose, we assess for ...

Emily held that FA provides teacher educators with the opportunity “to test students’ level of understanding of concepts”.

The literature has established that methods of measuring students’ learning are frequently characterised as a summative evaluation or FA. These teacher educators placed emphasis on the attainment of a standard by revealing students’ relative performance during the teaching and learning process. In the words of Black and Wiliam (2009), summative tests provide ways of extracting evidence of student accomplishment, and when utilised correctly can prompt
Feedback that moves learning forwards. From the perspective of the students, test information provides them with the chance to help one another and apply the test as a guide in scheduling their own revision.

**Formative assessment methods can be formal or informal**

Data from the interviews showed that participating teacher educators believed that FA strategies during teaching and learning could be formal or informal. This finding is consistent with the claim advanced by Kenyon (2019) that FA strategies that teachers use can be either planned or unplanned. Formal FA is also known as planned FA (Bell & Cowie, 2001). According to Bell and Cowie (2001), planned FA is used to generate permanent evidence of students’ thinking and can be organised at the beginning or the end of a topic, while informal FA happens concurrently during teaching and learning. The information gathered is used to build up a picture of students’ learning which can inform the planned FA.

One of the participants, Peprah, mentioned that “Actually, they come in many forms, but we assess them by giving them class exercise, quizzes, project work, group work, and presentations.”

In his submission Fordjour stated “We also assess them using classroom questioning and even observation.”

Questioning as an assessment strategy can be formal or informal, which offers teacher educators the chance to determine the most effective point to start their lesson from, as well as the appropriate level at which to begin new instruction. Utilisation of informal FA techniques offers teacher educators recurrent opportunities to gather data about their students’ progress towards the instructional goals in real time.

**Feedback practices**

Literature on the feedback aspect of FA has indicated that teachers’ feedback practices should ask questions like: “What knowledge or skills do I aim to develop? How close am I now? and What do I need to do next?” (Brookhart, 2017, p. 1) from the perspective of the students. Analysis of students’ assessment scripts showed that the nature of mathematics teacher educators’ feedback was consistent with students’ quiz papers and assignment scripts and did not give direction to the students on what to do next. Result from the document review showed that teacher educators involved in this study adapted the following annotations: \( M \) – *method mark*, \( A \) – *accuracy mark* and \( B \) – *mark for correct result independent of the method mark* in scoring students' work. That is, feedback on students’ written work reports was in the form only of marks, instead of providing students with suggestions for improving their performance by stressing strengths and weaknesses of their work. This finding contradicts the work of Black and Wiliam (1998) and Brookhart (2017), who argued that teachers' feedback on assessment tasks should focus on students' strengths and weaknesses and must highlight areas that require improvement by the students. In addition, feedback that moves students forward in their learning can be achieved through comment-only marking (Black & Wiliam, 2009), where teachers provide comments that address what the students need to do to improve, which should
be linked to the assessment criteria. Comments feedback is more effective than just using marks or letter grades (Leahy et al., 2005).

Based on the findings, it is established that in the realm of literature teacher educators have adequate knowledge of FA, which contradicts the claim advanced by Arrafi and Sumarni (2018) in their study that teachers’ understanding of FA is superficial.

Alignment of teacher educators’ understanding of formative assessment and Ghana’s assessment policy

In this section the researcher describes and analyses teacher educators’ understanding of FA with regard to the assessment policy on FA in response to the research question. To establish whether teacher educators’ conceptions align with the assessment policy, three policy documents on assessment in Ghanaian education were consulted, as presented in Table 2. Policy issues raised in the documents in relation to FA are compared with the findings of the study.

Alignment between policy and teacher educators’ conceptions of the definition of formative assessment

Table 2 shows that the meaning of FA provided by the National Council of Curriculum and Assessment (NaCCA, 2018) is similar to the views held by the mathematics teacher educators in this study, that FA forms part of the teaching and learning process. According to the NaCCA, FA is a process which should occur during the teaching and learning process while teaching is taking place and while learning is occurring. This means FA should be viewed and understood as an integral part of teachers’ pedagogical activities and should occur before teaching, during teaching and after teaching.
Table 2: Link between policy issues on formative assessment and study findings

<table>
<thead>
<tr>
<th>Policy document consulted</th>
<th>Policy issue raised</th>
<th>Findings and interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Definition of FA</strong></td>
<td></td>
</tr>
<tr>
<td>National Pre-tertiary</td>
<td>FA provides feedback</td>
<td>In this study teacher</td>
</tr>
<tr>
<td>Education Curriculum</td>
<td>and information</td>
<td>educators viewed assessment</td>
</tr>
<tr>
<td>Framework (NaCCA, 2018)</td>
<td>during a teaching</td>
<td>as an ongoing activity that</td>
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<td></td>
<td>and learning process</td>
<td>forms part of teaching and</td>
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<td>while teaching is</td>
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<td></td>
<td><strong>Purpose of FA</strong></td>
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<tr>
<td>National Pre-tertiary</td>
<td>FA serves the purpose</td>
<td>In this study, four teacher</td>
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<td>Education Curriculum</td>
<td>of improving learning,</td>
<td>educators indicated that</td>
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<tr>
<td>Framework (NaCCA, 2018)</td>
<td>and shaping and</td>
<td>assessment could be used to</td>
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<td></td>
<td>directing the</td>
<td>gather evidence about the</td>
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<td></td>
<td>teaching and learning</td>
<td>teaching and learning and to</td>
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<td></td>
<td>process</td>
<td>evaluate students’</td>
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<td></td>
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<td>acquisition of knowledge</td>
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<td><strong>FA strategies</strong></td>
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<td>National Teachers’</td>
<td>Integrate a variety</td>
<td>In this study, teacher</td>
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<td>Standards for Ghana</td>
<td>of assessment modes</td>
<td>educators recognised the</td>
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<td>guidelines (National</td>
<td>into teaching to</td>
<td>importance of integrating</td>
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<td>Teaching Council,</td>
<td>support learning:</td>
<td>and using multiple</td>
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<td>2017:30)</td>
<td>examples, tests,</td>
<td>assessment methods and</td>
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<td></td>
<td>quizzes, assignments/</td>
<td>strategies</td>
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<td></td>
<td>homework, etc.</td>
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<td></td>
<td><strong>Nature of feedback</strong></td>
<td></td>
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<tr>
<td>National Pre-tertiary</td>
<td>Good assessment uses</td>
<td>In this study, teacher</td>
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<tr>
<td>Education Curriculum</td>
<td>multiple methods.</td>
<td>educators’ feedback on</td>
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<td>Framework (NaCCA, 2018)</td>
<td>Assessment should</td>
<td>students’ written work</td>
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<td>be comprehensive</td>
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<td>marks only</td>
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Alignment between policy and teacher educators’ conceptions of the formative purpose of assessment

When considering the purpose of FA, mathematics teacher educators aver that the aim of FA is to gather evidence about the teaching and learning and to evaluate students’ acquisition of knowledge. This indicates that FA is designed to generate information about students’ performance, and based on that information students’ learning can be supported and teaching modified (Black & Wiliam, 2009). This suggests a close alignment of teacher educators’ understanding and policy in relation to the purpose of FA.

Alignment between policy and teacher educators’ conceptions of formative assessment methods

Teacher educators are required to employ FA techniques during their instruction and it is thus imperative that these educators have a clear understanding of these techniques or strategies. As presented in Table 2, the National Teaching Council (2017) of Ghana stated in the National Teachers’ Standards document that teachers should incorporate a diversity of assessment methods.
modes into teaching to support learning. This view was reaffirmed by the NaCCA, which states that good assessment uses multiple assessment methods. These two statements align with each other and confirm what is reported in the literature (Siegel & Wissehr, 2011) – that there is a need for teachers to adopt multiple assessment methods because a single method will measure only some aspects of students’ learning. Matching these policy issues with teacher educators’ conceptions of FA methods or strategies revealed that teacher educators recognised the importance of adopting a variety of assessment modes in daily practices in order to respond to students’ learning needs. Teacher educators exhibited an understanding of diverse methods of assessment by citing a number of them.

Alignment between policy and teacher educators’ conceptions of the form of feedback

Table 2 shows that the type of feedback which teacher educators provide was not aligned with what has been stated in the National Pre-tertiary Education Curriculum Framework by the NaCCA (2018). According to the NaCCA, in using FA teachers should indicate what is good about a piece of work and why it is so; it should also indicate what is not good and how the work could be improved. This suggests that teachers are required to provide feedback to students’ work in the form of comments. However, analysis of students’ assessment scripts revealed that teachers’ feedback reports took the form of marks instead of comments for shaping students’ learning. The lack of alignment on the form which feedback should take might be the result of educators’ superficial knowledge on how to provide feedback that moves learning forward.

Conclusion and recommendation

This study looked into the extent of alignment between mathematics teacher educators’ understanding of FA and policy on assessment in the context of Ghana. For conceptual understanding of the alignment it is essential to compare teacher educators’ knowledge of FA on generic principles which underpin FA and are captured in the assessment policy of Ghana. These include: (i) definition or meaning of FA, (ii) purpose of FA, (iii) FA strategies, and (iv) the nature of formative feedback.

The findings in this study indicate that out of the four issues compared with teacher educators’ understanding, three of them were in close alignment with policy. These issues include the definition of FA, the purpose of FA and FA methods. The study also provided evidence of a misalignment in one of the areas, which is the nature of feedback that teacher educators provide to their students.

This suggests that teacher educators do not have sufficient knowledge on giving feedback which points out to students the strengths and weaknesses of their work and gives direction on what to do in order to improve. We therefore recommend a professional development programme to train teacher educators on how to give feedback comments that move learning forward.

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LEARNING TO NOTICE LEARNERS’ MATHEMATICAL THINKING WHILE CO-ENACTING INSTRUCTION
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Abstract

The study critically examines in-service teachers’ opportunities to develop their ability to learn professional noticing when co-enacting instruction. It focuses particularly on exploring what as well as how teachers notice when the participants pause the instruction by initiating a Teacher Time Out (TTO) in the enactment phase of learning cycles of enactment and investigation. Fourteen primary school in-service teachers collaborate with teacher educators and participate in TTO discussions. A framework of noticing was applied in the analyses with the aim of shedding light on the ways in which these discussions enable teachers to collectively learn to notice learners’ thinking. Findings from the analyses of all the 189 TTOs reveal that in 45 of the TTOs, teachers made sense of individual learners’ mathematical thinking (focused noticing), and also used evidence from the situation in the lesson to reason and elaborate on important teaching and learning issues based on learners’ thinking (extended noticing). These are examples of higher-level noticing.

Introduction

A critical role of teacher education and professional development (PD) is to equip teachers with teaching practices that support learners from diverse backgrounds. Such practices have been referred to as ambitious because they support the learning of all learners “across ethnic, racial, class and gender categories” and because they “aim to deepen learners’ understanding of mathematical ideas” (McDonald et al., 2013, p. 385). One core activity of ambitious teaching practices is sizing up learners’ ideas and responding (Ball et al., 2001). Novice teachers are, however, found to have had limited exposure to interpreting learners’ mathematical thinking during teacher education (Jacobs et al., 2010). They are often able to talk about ambitious teaching practices, but the enactment of such practices is more challenging (e.g. Sleep & Boerst, 2012; Thompson et al., 2013). Learning ambitious teaching practices takes time (e.g. Kinser-Traut & Turner, 2020) and the enactment of such practices is thus important, also for mathematics teachers’ PD (Kavanagh et al., 2019).

In this study, learners’ thinking refers to the strategies, representations and reasonings they use. Learners’ thinking is a coherent and logical approach to mathematical reasoning that often differs from what mathematicians and other adults use. For teachers, noticing learners’ thinking is essential and research has suggested that developing the ability to notice can be learned through scaffolded support and collaboration (e.g. Star et al., 2011). In the Mastering Ambitious Mathematics teaching project (MAM), in-service teachers collaborated in learning cycles of enactment and investigation (for learning cycles, see methods section) so they could develop their ability to notice learners’ thinking and build on this in their teaching. For the purpose of this study, the analysis aims to shed light on the ways in which learning cycles enable teachers
to collectively learn to professionally notice learners’ thinking. What as well as how teachers notice (van Es, 2011) is the focus here. Our work is grounded on the underlying assumption that “teacher noticing is worthy of study because teachers can be responsive only to what has been noticed” (Jacobs & Spangler, 2017, p. 192). The present study builds on findings from an exploration of the co-planning discussions in the learning cycles in MAM, suggesting that the teachers focused on particular learners’ thinking (focused noticing) and on both learners’ thinking and teacher’s pedagogy (extended noticing) (Fauskanger & Bjuland, in press).

**Theoretical background**

Professional noticing builds on the concept of professional vision (Mason, 2002; Sherin & van Es, 2003) as a process through which teachers make sense of what occurs during instruction and make plans to respond to learners’ thinking (Sherin et al., 2011). Mason (2002, 2011) presents noticing as a discipline and as a collection of practices. Ball (2011, p. xii) sees noticing “as a practice essential to attending to learners, to the domain for which the teacher is responsible, and to connections between the learners and the domain”. Noticing is consequential, it is an awareness that enables action (Mason, 2011) and skilled teachers are quicker to identify situations that require intervention (Miller, 2011) or action. Noticing has consequences for what a teacher observes and does not observe, and for what a teacher does and does not do. Because it can lead to changed practices, noticing is thus “a key component of teaching expertise and of mathematics teaching expertise in particular” (Sherin et al., 2011, p. 79).

Teacher noticing is conceptualised in a variety of ways (Miller, 2011), but the two interrelated and cyclical processes of attending to and making sense of particular events in an instructional setting are often involved (Sherin et al., 2011). For example, Star et al. (2011) include what a teacher attends to as well as what the teacher decides not to attend to in their conceptualisation of noticing. For the purposes of this paper, the term noticing is considered to include: a) attending to learners’ thinking throughout learning cycles, b) reasoning about learners’ thinking, and c) making informed teaching decisions according to an analysis of these observations (e.g. Jacobs et al., 2011; van Es, 2011).

When working closely with a group of experienced teachers in the U.S., Empson and Jacobs (2008) found that the teachers were unprepared to hear and see learners’ mathematics. If a teacher is to learn to notice learners’ mathematics, an interrelated and situated set of skills for attending to their mathematics is required; skills that are specialised and therefore require a significant shift in how teachers conceptualize their role (Empson & Jakobs, 2008). Although not usually developed in teacher education programmes (e.g. Ball, 1993; Fennema et al., 1996), and taking years to learn (e.g. Empson & Levi, 2011; Steinberg et al., 2004), these skills are learnable with sustained PD (e.g. van Es & Sherin, 2008). Professional noticing is thus important for cycles of enactment and investigation for PD. The present study draws to a large degree on the analysis of (student) teachers’ noticing using video (i.e. Roth McDuffie et al., 2014; Star & Strickland, 2008; van Es & Sherin, 2008). However, our work augments the literature by focusing on context, i.e. situating teachers in the authentic work of teaching through learning cycles. Given this, and building on how they plan to notice (Fauskanger &
Bjuland, in press), it was important to investigate what teachers notice when they co-enact instruction.

In the co-enactment in the MAM project, the participants can pause the instruction by initiating a Teacher Time Out (TTO) so they can think out loud together in the moment, discuss how the teacher might respond to learners’ contributions and determine the direction of the further instruction (Fauskanger, 2019; Fauskanger & Bjuland, 2019). After the TTO, instruction continues. TTOs allow the teachers to collectively consider in-the-moment decision-making and then try out the ideas. It can be argued that TTO discussions from participants might distract the learners as such pauses might interrupt the flow of the lessons. However, research has shown (e.g. Gibbons et al., 2017; Fauskanger, 2019) that this is not necessarily an issue. Learners have been informed that TTOs (with a duration often just up to ten seconds) might occur during lessons since such situations can be seen as a learning context for the participants.

With the aim of shedding light on the ways in which the TTOs enabled the teachers to collectively learn to notice learners’ thinking by exploring what and how they notice (van Es, 2011), Fauskanger & Bjuland (in press) analysed the co-planning sessions within the MAM project. When concluding their study, they write that the co-planning sessions appear to be contexts where teachers can practise how to build on learners’ mathematics and develop the ability to notice – in particular, what to notice (van Es, 2011). While this previous study offers the field insight into co-planning in the context of PD, the researchers point out that in order to make clearer conclusions, we need to develop our understanding of how the different elements in the learning cycles enable teachers to collectively learn professional noticing. Exploring what as well as how teachers notice (van Es, 2011, see Table 1) in the enactment phase of the learning cycles is one way to meet this call. Bearing this in mind, the present study explores TTOs in the co-enactments. The following research question is addressed: How can the participants’ TTO discussions in the enactment phase of the learning cycles provide them with opportunities for learning depth of noticing?

**Methodology**

The present study draws on Lave’s (1991) description of learning, thinking and knowing as “relations among people engaged in activity in, with, and arising from the socially and culturally structured world” (p. 67). Thus, sociocultural views on teacher learning inform the study. Learning is understood as it emerges in activities, and from this perspective, teacher learning includes developing the ability to engage in particular practices. Learning cycles (Figure 1) were designed to engage teachers in learning such ambitious teaching practices as professional noticing. In designing the learning cycles, we gave the teachers repeated opportunities to co-plan, rehearse, co-enact and reflect upon a set of intentionally selected instructional activities (e.g. choral counting, quick images, number strings) embedded in learning cycles with teacher educators as supervisors. Moreover, the activities reduced the complexity of the teachers’ learning by supporting them in eliciting learners’ thinking and in making judgments on how to respond in principled, instructive ways (Kavanagh et al., 2019; Lampert et al., 2013).
Throughout the cycle, the teachers were encouraged to 1) ask questions, explain and justify their mathematical and instructional ideas, 2) find multiple strategies and 3) try to understand what other participants said and did. Thus, a setting was developed where teachers could be engaged together in the joint enterprise of learning professional noticing in which questions and disagreements were viewed as a productive part of the enterprise. Fourteen Norwegian primary-school teachers worked together in two groups in repeated learning cycles. Each group was guided by a supervisor. The participants met for nine full learning cycles over the course of two years, producing eighteen (18) videotaped cycles. In this paper, the analysed data material has been taken from video recordings of co-enactments in all the cycles. In these co-enactments one teacher was teaching the co-planned lesson while the other teachers and the supervisor were observing.

Van Es (2011, p. 137) identified three main areas within which noticing develops: “what stands out to teachers when they observe teaching, the strategies they use to analyze what they observe, and the level of detail at which teachers discuss their observations” (van Es, 2011, p. 137). This framework of noticing (Table 1) includes an identification of “what is noticed and how teachers’ reason about what they observe” as well as “a trajectory of development in these two dimensions from Baseline to Extended Noticing” (van Es, 2011, p. 138). In the present study, this framework was used to analyse the depth and analytical stance of noticing in teachers’ TTO discussions throughout the co-enactments.

Table 1. Framework for learning to notice learners’ mathematical thinking (van Es, 2011, p. 139).

<table>
<thead>
<tr>
<th>Level 1 Baseline</th>
<th>Level 2 Mixed Level</th>
<th>Level 4 Extended</th>
</tr>
</thead>
<tbody>
<tr>
<td>What teacher’s notice</td>
<td>Attend to whole class environment, behaviour, and learning,</td>
<td>Pedagogy and teacher pedagogy begin to attend</td>
</tr>
<tr>
<td>attend teacher to teacher</td>
<td></td>
<td>learners’ mathematical thinking to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>between learners’ mathematical</td>
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<td></td>
<td></td>
<td>relationship</td>
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</table>

Figure 1. Cycle of enactment and investigation for professional development (adapted from Lampert et al., 2013, p. 229).
What teachers notice captures both whom they notice and the topic of their analysis. Whom they notice concerns whether the participants focus on the class as a whole, learners as a group, particular learners, the teacher responsible for enacting instruction or themselves (van Es, 2011). Topic refers to issues they identify, “such as remarks focused on the pedagogical strategies, behavior or mathematical thinking, or the classroom climate” (van Es, 2011, p. 138). How teachers analyse what they notice includes both their analytical stances and levels of depth. Analytical stance refers to the approach teachers take to their analysis and captures whether the participants inquire into teaching and learning as well as whether they evaluate or
interpret what they observe. When evaluating, the participants make “uninformed judgments about what was good or bad or should have been done differently” (van Es, 2011, p. 138). Interpreting refers to the teachers’ efforts “to reason about what they observe, to understand the roots of an idea, and to explain what was meant by a particular statement, drawing, gesture, or expression” (van Es, 2011, p. 138). Inspired by Karlsen and Helgevold (2019), our analytical stance has been to identify whether the teachers evaluate, describe or make claims (low-level noticing) or whether they interpret, explain and give reasons in the teaching situation (high-level noticing).

Bearing this in mind, in the analyses all 189 TTOs were transcribed and coded using the framework of noticing (van Es, 2011). This framework includes four levels of noticing – baseline, mixed, focused and extended levels (Table 1). Each level represents what teachers in collaboration with teacher educators notice as well as how they notice. Their attending to whole class observations or teacher pedagogy represents lower levels of noticing. At higher levels of noticing, the focus is on particular learners or connections between teaching and learners’ learning. Descriptive and evaluative comments represent a lower level of noticing, while higher levels of noticing are characterised by a focus on learners’ mathematics. Lastly, a qualitative in-depth analysis of coded TTOs was conducted to identify and explore examples of noticing on different levels. In this paper, an overview of noticing in the TTOs will be presented, followed by representative examples from selected TTOs chosen from the data material to present our findings. It is important to emphasise that teachers might be noticing in the enactment outside of TTOs as well, but for the purpose of this paper, only TTOs are analysed.

Findings and Discussion

Table 2 summarises the four levels of noticing identified in the 189 analysed TTOs. In 64 of the TTOs there were no signs of noticing, indicating that the teachers were not concerned with themselves and their own practices (baseline noticing, Level 1), nor were they attending to particular learners’ mathematical thinking (higher levels of noticing). Many of these TTOs (no noticing) were often brief, lasting only a few seconds. This dimension was often found at the end of the lessons, or when the teachers were discussing practical issues. One typical example of a TTO at the end of the lesson (TTO4, Gr2, Session 1) illustrates this. Here, one of the observing teachers (OT1) praises the learners: “Lucky teachers who get you for learners, I must say”. This was followed by a brief supportive response “Yes” from the teachers before OT1 continued to praise: “You guys impress me”. The following example (TT013, Gr2, Session 2) illustrates practical issues when the teacher writes on the board and says: “Oops, now it went a little too quick, but …”, followed by the supervisor who responds: “That’s okay”.

Table 2. Overview of levels of noticing in the TTOs.

<table>
<thead>
<tr>
<th>All TTOs</th>
<th>No noticing</th>
<th>Baseline</th>
<th>Mixed</th>
<th>Focused</th>
<th>Extended</th>
</tr>
</thead>
<tbody>
<tr>
<td>189</td>
<td>64</td>
<td>53</td>
<td>27</td>
<td>25</td>
<td>20</td>
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</table>
When analysing the content of the other TTOs, there were many instances (53) where the participants appeared to be concerned with the whole class environment and teacher pedagogy (baseline noticing, Level 1). The following TTO (TTO17, Gr3, Session 4) illustrates this level when the teacher has tried to get the learners to answer why the factor order does not matter when dealing with the associative property of multiplication. She takes a TTO and asks the other participants: “How long should I stretch it before I…should I say what we’re aiming for? Or should we take it…” They agreed on the teaching strategy and the teacher went on with the teaching.

In the following TTO (mixed noticing), the teachers are primarily attending to teacher pedagogy, but there are signs of being concerned with the learners’ thinking. The focus of the discussion is to find patterns and connections in a quick image (TTO5, Gr2, Session 3), and the teacher has asked the learners if they see more connections. The learners are silent, but the supervisor has heard something one of the learners has said in a low voice, and she wants to include this learner’s initiative in the discussion: “I want to take a time-out. Is there anyone here who can help (looks to the other teachers), who heard what she just said? I think there might be”. The participants confirm that one of the learners said something in a low voice, and the supervisor suggests that the teacher should ask the learner to repeat what she said, which the teacher thinks is a good idea. This example of a TTO indicates that the discussion is general with little mathematical content, but the teachers are beginning to attend to particular learners’ thinking.

As can been seen from Table 2, there were also many instances (25 focused, 20 extended) in which the teachers made sense of learner thinking and used evidence from the situation in the lesson to reason and elaborate on important teaching and learning issues (Karlsen & Helgevold, 2019; van Es, 2011). We suggest that these 45 TTOs are very important situations while co-enacting instruction in order to learn to notice learners’ mathematics. In the following, we will delve into two of these TTOs (high-level noticing) to illustrate the teacher’s opportunity to explain and reason about learners’ mathematics and to make informed teaching decisions on the basis of these observations made in the moment of the teaching situation (e.g. Lamb et al., 2011; van Es, 2011).

In TTO2 (focused noticing, Gr2, Session 6), a word problem in which four students should run an equal distance and altogether 100 metres is introduced and one of the learners has suggested the following symbolic representation: $100 : 4 = (100 : 2) : 2)$. The teacher starts to visualise the mathematical representation on a number line by illustrating with jumps of 25 at a time. Then the supervisor asks the following question:

**Supervisor:** Can I ask for a time-out?
**Teacher:** Sure.
**Supervisor:** Can you draw it like she has, who was it who said it, was it Learner [learner’s name]?
**Teacher:** Yes, I can, sure.

From this TTO, we observe that the supervisor is attending to this particular learner’s thinking by suggesting that the teacher should make the visualisation on the number line in accordance
with the learner strategy. In this situation, the supervisor helps the teacher to clarify the learner strategy and to interpret and explain the link between the visual and symbolic representation in the number string. The difference between students’ thinking when representing 100 : 4 as (100 : 2) : 2) and 4 × 25 respectively on a number line is clarified. The teacher continues the lesson by summing up what has been said by the learner.

In the highest level of noticing (extended), there is a clearer relationship between individual learners’ mathematical thinking, and between teacher strategies and the learners’ thinking. In this session (TTO1, Gr2, Session 1), the activity is choral counting in which the learners are challenged to count from the number 19 with jumps of 19 (19, 38, 57 and so on). Before the actual TTO, they have discussed solutions to the addition 190 + 19. The learners have offered several suggestions, written on the board. Two alternative solutions seem to receive the most support from the learners: 209 and 219. The teacher is uncertain about how to continue the teaching and she takes a time out:

Teacher: Can I ask for a time-out here? I’m getting a little stuck here. In relation to…in a way… Ah, you know, ah, what am I supposed to do with these suggestions now?

OT1: You can show them visually, like, how one like took 190 and then added a ten and a nine.

OT2: On a number line.

Teacher: Yes, for example on a number line, yes. That was a good idea.

The teacher continues by illustrating (190 + 10 + 9) on a number line.

The teacher has observed learner solutions (what, see Table 1) written on the board. She is uncertain about how to proceed and the how-question indicates that she is asking for support from the other observing teachers. This question also includes an invitation to the other teachers to make suggestions for possible explanations, helping the learners to understand why 209 is a correct solution. Two of the observing teachers give advice (how, see Table 1) for bringing the teaching forward. OT1 suggests visualising the addition in two steps by decomposing 19 into 10 + 9 by first adding ten to the next hundred (190 + 10) and then adding 9 (190 + 10 + 9) in order to arrive at the solution (209). Building on OT1’s suggestion, OT2 elaborates on the visualisation by proposing the idea of illustrating the additions on a number line. The teacher expresses that the idea of using a number line is a good teaching strategy and follows up the teaching to illustrate 190 + 10 + 9 on a number line.

In these two important TTO situations (focused and extended noticing) while co-enacting instruction, the participants are particularly concerned with the learners’ mathematical thinking. We observe that different participants ask for a TTO. In the first situation, the supervisor (focused) helps the teacher to clarify a learner strategy while in the other situation the teacher (extended) asks for the TTO to discuss with the other participants how to deal with different solutions from the learners.

These results are interesting and promising. They differ from studies of teacher noticing in video clubs (e.g. Roth McDuffie et al., 2014; Star & Strickland, 2008; van Es & Sherin, 2008) and in post-lesson discussions in lesson study cycles (e.g. Karlsen & Helgevold, 2019). It seems
that the co-enactment phase in learning cycles invites teachers to learn higher levels of noticing than in the two above-mentioned approaches. At these higher levels, participants do not only attend to teacher pedagogy and learner behaviour, but also to particular learners’ mathematics and to teaching strategies building on learners’ mathematics (van Es, 2011). According to van Es (2011), the video clubs supported the participants in shifting from baseline to advanced levels of noticing. The present study has not focused on the differences between teachers’ noticing in the first MAM sessions to the last ones but if this had been done it might have led to similar results. It seems, however, that learning cycles with co-enactments and opportunities to ask for TTOs are promising when it comes to the participants’ opportunities to learn professional noticing. Compared to lesson study reflection sessions (e.g. Karlsen & Helgevold, 2019), TTOs in co-enactments in learning cycles seem to invite teachers to attend to the relationship between particular learners’ mathematical thinking as well as the relationship between teaching strategies and learners’ mathematical thinking. Furthermore, learning cycles seem to invite the participants to make connections between events and principles of teaching and learning and at the same time propose alternative solutions according to these interpretations. According to van Es (2011), this kind of professional noticing relates to high levels of noticing.

**Conclusion and implications**

Teacher Time Outs (TTOs) in co-enactments in learning cycles of enactment and investigation (Figure 1) in the MAM project have been analysed to provide insight into how these co-enactments create situations for teachers’ collective learning of noticing learners’ mathematical thinking. It seems that TTOs in co-enactments are contexts where teachers can learn to “size up” learners’ ideas and respond to them (Ball et al., 2001). When working together in TTOs, the participants practise how to build on learners’ thinking (Empson & Jacobs, 2008), as has been endorsed in many reform documents (for Norway and Malawi see Utdanningsdirektoratet, 2019; Ministry of Education, Science and Technology, 2013). Developing the ability to notice – both what to notice and how to notice (van Es, 2011, Table 1) – can be learned through scaffolded support and collaboration (e.g. Star et al., 2011) as in the learning cycles in the MAM project.

While this study provides the field with insight into co-enactments in learning cycles in the context of PD, more research is needed. Compared to studies of teacher noticing in video clubs (e.g. Roth McDuffie et al., 2014; Star & Strickland, 2008; van Es & Sherin, 2008) and in lesson study cycles (e.g. Karlsen & Helgevold, 2019), the learning cycles of enactment and investigation (Lampert et al., 2013; Mc Donald et al., 2013) appear to invite teachers to learn higher levels of noticing. However, in order to be able to make clearer conclusions we need to provide systematic descriptions of each element of the learning cycles, also in contexts outside of the MAM project, such as different African contexts and in terms of developing understanding of how the different elements enable teachers as well as student teachers to collectively learn professional noticing. Moreover, studying possible ways of learning within projects like MAM might lead to changes in teachers’ classroom practices and will also be of importance for future research.
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MATHEMATICAL INSTRUCTIONAL EXPLANATIONS WITH A SPATIAL COMPONENT
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Abstract
The purpose of this paper is to advance the research conversation on the nature of instructional explanations by a proposal to include an “explanation with a spatial component” as a feature of an instructional explanation. Literature on instructional explanations focuses on either the written or the verbal form but not on both forms together. This paper illustrates two examples of “explanations with a spatial component.” These explanations consist of what is written and how it is written on the chalkboard together with teacher’s utterances to highlight explanations for different purposes. This is a component of an instructional explanation illuminated through a grounded analysis of transcripts of classroom observations of two teachers’ lessons on two different mathematics topics.

Introduction
Imagine the following staffroom conversation between teachers:

Tsebo Eish. Teaching is hard. When we see maths lessons in other schools, teachers have overhead projectors, computers, wi-fi.
Ndívho Ja. They screen you-tube videos and use fancy software for different topics. What do we have?
Ngempela We might not have fancy stuff but I’ve learnt to make do with what we have.
Tsebo What do we have to help us?
Ngempela We have a chalkboard. Make use of it. Not in the normal way like write wherever there is space. Use it creatively.
Ndívho How can you get creative with a chalkboard?
Ngempela I’ve learnt to arrange examples that are closely related but not the same very close together.
Tsebo How would this help?
Ngempela It helps to focus kids’ attention. You can move back and forth explaining the differences and similarities between them, what each represents and so on. It depends on what you want to show the kids. Having them close together helps them to follow your talk when you move between them.
Tsebo Sounds interesting. Worth a try
Ndívho I’ll try it too
This fictional scenario illustrates the focus of this paper – to advance the theory on the nature of instructional explanations. I argue that an instructional explanation encompasses metaphorically a spatial component. By “explanation with a spatial component” I mean how a teacher deliberately lays out work on the chalkboard to accompany her verbal utterances, and can “move around” the space of examples and working thus created. I use “space” in both the physical and metaphorical sense. The physical space is a reference to the close proximity of what is written on the chalkboard. A metaphorical space is that between what is written and the verbal utterances of the teacher that make explicit the purpose of the explanation. I provide two examples of explanations with a spatial component and thus continue the research conversation on the nature of instructional explanations.

Literature on instructional explanations focuses on either written or verbal forms but not on a combination of both. For example, Morgan (1998) focuses on written explanations in texts with attention on how words are written to illustrate the “progression of the story” (p. 87). However, the role of the teacher’s verbal utterances in supporting the written form of an explanation is not in focus. Leinhardt (2001) provides a description of teachers’ verbal explanations. For example, she considers an explanation to consist of examples, discussions that connect these examples to particular rules, and discussions that limit the applicability of the rules. She, however, does not consider what is written (in text books or other written forms) in conjunction with the spoken word of the teacher.

Wittwer and Renkl (2008) posit that instructional explanations are characterized according to the goal of an explanation, to support other teaching activities and provided in verbal or written forms. I zoom into this third category and argue that explanations can encompass both written and verbal forms. The written component that I focus on is work written on the chalkboard. The written and the verbal components complement each other rather than one being secondary to the other. A written explanation on its own may not make explicit the purpose of the explanation and neither will a verbal explanation on its own. I therefore use the words “complement each other” to illustrate how the written and verbal together support an explanation. The purpose of this paper is to illustrate how deliberate attention to the layout of board-work complement teachers’ utterances. The question I address is “What insights might, considering the spatial component of an instructional explanation, add to current literature on explanations?”

I illustrate how deliberate attention to lay-out of written work on the chalkboard is accompanied by verbal utterances of the teacher to provide explanations for different purposes. I illustrate, using two examples, how “moving” between the space of the written and verbal forms add to the literature. In the first I illustrate how the teacher lays out four different but related questions and their solutions on the chalkboard accompanied by his utterances to provide an explanation that illuminates how the questions link to each other. The accompanying utterances of the teacher attend to these relationships which develop Leinhardt’s point about the need to link different mathematical ideas but the enactment of which she does not elaborate. I provide a further example of another teacher placing contrasting examples next to each other and how he...
“moves” between them to provide an explanation underscoring their different solution strategies.

Together, these examples enable a view of explanations that are not linear but as involving a back and forth movement between the space of the written and verbal form to illuminate the mathematical idea in focus.

**Literature Review**

Much of the theory on teachers’ explanations in the classroom builds on Leinhardt’s (2001) work. She considers four different types of explanations i.e. common, disciplinary, self and instructional explanations. I focus on instructional explanations as they are used specifically to teach the subject matter to others. I view instructional explanations as those offered by the teacher to the learners rather than explanations from text books, or those between learners. Leinhardt (2001) describes an instructional explanation as “containing an instance of something to be explained” (p. 341). This description is circular; using “explaining” to describe what an explanation contains does not specify what an explanation consists of and so requires further elaboration.

Other literature provides many other features of an explanation. For example, explanations should take into account learners’ prior knowledge (Stein & Kucan, 2010); the content of an explanation should be technically correct and unambiguous (Mancosu, 2008) and should take into consideration learner misconceptions (Webb & Palinscar, 1996). Here, I contribute to the literature by adding that an instructional explanation consists of the interplay and connections between written and verbal forms of communication with particular attention to chalkboard use.

Chalkboard use in instruction is, however, not widely researched except in Japan where research illuminates how the chalkboard is used for different purposes. For example, work on the chalkboard is seldom erased to retain a record of the progression of the lesson and to compare and contrast student ideas (Yoshida, 2005). The chalkboard is also used by learners to record and explain their ideas and then by the teacher to connect different ideas from different learners (Tan, Fukaya, & Nozaki, 2018). How the teacher connects the different ideas written on the chalkboard though is not a focus in the literature on chalkboard use. This article contributes in elaborating on this aspect of explanations.

Venkat and Naidoo (2012) noted the lack of connections between different mathematical ideas in South African classrooms. The disconnect between the OoL and teacher explanations to support activity across primary and secondary schools in South African mathematics classrooms was noted by Venkat and Adler (2012). Mhlolo (2012) claims that helping teachers on how to offer explanations that link different mathematical ideas may result in more effective mathematical instruction. The results of my study on how the verbal and written forms contribute to providing explanations that link mathematical ideas will be an important contribution to enhance instruction particularly in South African mathematics classrooms.
Study Context

The two teachers participated in a professional development course, called Transition Mathematics (TM1) offered by the Wits Maths Connect Secondary (WMCS) project, a research and development project at the University of the Witwatersrand. The course focused on improving the mathematical and pedagogical content knowledge of teachers teaching mathematics at the grade 8, 9 and 10 levels. Teachers were introduced to the Mathematics Teaching Framework (MTF) focusing on four components of mathematics teaching. One of the components is “explanatory communication” which focuses on the language used and how examples are selected and used to make clear the mathematics made available to learn.

Methodology

The research involves a qualitative multiple case study approach within an interpretivist paradigm to “generate an in-depth, multi-faceted understanding of a complex issue” in a realistic context (Crowe et al., 2011, p. 1)

The teachers were purposively chosen based on their performance in the TM1 course and therefore had engaged substantially with instructional explanations through the MTF. The two teachers reported on here have a tertiary mathematics qualification and a minimum of five years’ experience in teaching mathematics.

I consider both teachers to have strong mathematical content knowledge because of their active course participation and above-average performance on assessments that dealt with both content and pedagogical content knowledge.

Data from the two teachers was collected through video-records and classroom observation of their Grade 10 lessons on two topics: number patterns and solving quadratic equations by factorisation. Informed consent was sought by providing all teachers, learners as well as the parents of learners with a participant information sheet as well as a signed consent form. Participants were informed that they were under no obligation to participate and that they could withdraw from the study at any stage. They were informed that pseudonyms will be used in all reporting of the study. Learners were also informed that the camera would be focused on the teacher and not on them. However, five learners in one of the classrooms changed their seating arrangements so that they could be out of the line of the camera.

Analysis reported here was conducted using grounded theory, the goal of which is theory development. In alignment with Strauss and Corbin’s (1994) theory of analyzing data by breaking it up into smaller parts identified by their core idea, I divided the transcriptions of the video records into episodes. I identified episodes by what was perceived to be shifts in the object of learning (ooL) i.e. learner skills and capabilities (Marton & Pang, 2006) to be developed in each episode. The ooL in each episode was not explicitly stated by the teacher but is my interpretation of what was being explained by the teacher in that part of the lesson.

One of the limitations of grounded theory is that the breaking down of data into codes and categories may result in the researcher losing sight of the bigger picture present in the data (Leatham, 2019). Instead of a line by line analysis I analysed the episodes holistically in terms of the mathematics made available to learners and how the explanation was facilitated. I did
this by writing memos. Memos involve the writing of ideas, notes on surprising ideas, hunches, suggestions for further inquiry etc. that occur to the researcher during the analysis of data to aid in viewing the data at a higher conceptual and analytical level (Corbin & Strauss, 2014). This enabled me to move back and forth between categories to find relationships between ideas in the memos.

My memos consisted of posters created of the episodes in each lesson. This enabled me to explore the main mathematical idea of each episode and how the teacher went about conveying this idea to learners. Posters illuminated themes arising from each episode of each lesson.

According to Strauss and Corbin (1994), codes can be derived directly from the data or from existing theoretical constructs. I used literature on explanations to compare with my findings. I considered those features of explanations that are either not addressed by the literature or that needed further elaboration. For example, Leinhardt (2001) posits that an explanation should link together various mathematical ideas but does not elaborate on how this is enacted in the classroom. Creating posters highlighted those episodes which attended to the linking of mathematical ideas. Once episodes were identified, I examined in detail, how the teacher linked these mathematical ideas. For example, a teacher linked ideas by drawing attention to the layout of examples on the chalkboard. This layout was different to typical teachers writing on the chalkboard from left to right. I recorded this under a broad heading titled “chalkboard use”. However upon a more detailed analysis I found that there were different ways in which the chalkboard was used for different purposes. For example, correct and incorrect solutions of particular examples were laid out side by side to highlight common errors whereas at other times closely related examples were placed side by side to highlight the relationship between the different questions/solutions. However, explicit attention to these relationships was required. The verbal utterances of the teacher illuminated the relationship between verbal and written forms of instructional explanations. I called this an explanation with a spatial component.

**Data Analysis**

I illuminate explanations with a spatial component by analyzing and discussing two illustrative examples.

**Example 1: Explanation with spatial component showing relationships between questions**

Tsebo’s (pseudonym) first lesson on Linear Number Patterns focused on terminology, finding the next few terms in a given sequence, verbally describing sequences and finding the general term intuitively. I provide an illustration of an episode in the second lesson which followed a review of homework from the previous lesson. This part of the lesson centred on answering the three questions in Fig.1.

**Fig. 1: Tsebo’s questions based on given sequence**

<table>
<thead>
<tr>
<th>Given the sequence 23; 19; 15; .....</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Find the general term if it is arithmetic.</td>
</tr>
<tr>
<td>2. Find the 15th term.</td>
</tr>
<tr>
<td>3. Which term in the sequence is equal to −53†</td>
</tr>
</tbody>
</table>

†Note: The symbol † indicates a footnote, typically used to denote a correction or additional information that is not essential to the main text. In this context, it might signify that the term in question is not equal to −53, or it could be a placeholder for further details.
The first question requires confirming that the sequence is arithmetic (which I refer to as 1(a)) before finding the general term (referred to as 1 (b)).

The goal of this episode, as is suggested by what was made available to learners, was to make explicit the relationship between all questions relating to the given pattern. Tsebo provided an “explanation with a spatial component”, consisting of a specific layout of examples on the chalkboard accompanied by his utterances to clarify particular mathematical ideas. The spatial aspect of the explanation does not only relate to the physical arrangement of the questions but also represents the metaphorical “movement” connecting between the written (physical) and verbal space between them to highlight their inter-relationships. I first show how Tsebo laid out what was written on the chalkboard before a discussion of how his verbal utterances and gestures contributed to the explanation.

He wrote the questions and their solutions on the board as shown in fig. 2.

As seen in fig. 2, Tsebo wrote the four solutions with 1(b) written below 1(a). He then ruled a vertical line to the right of both before arranging questions 2 and 3 below each other. The result was that all four solutions were eventually laid out side by side on the chalkboard. A small portion of the board was used despite there being more chalkboard space available. This close physical arrangement suggests that all four questions are inter-related but only provides a visual representation of the solutions. Tsebo’s very specific arrangement of the solutions was accompanied by his utterances which complemented the physical layout of the solutions on the board in making these relationships explicit. The verbal and the written were connected to each other by the teacher’s gestures which contributed to the whole explanation.
Fig 3 contains a diagrammatic version of his explanation with a spatial component.

Fig. 3: Diagram illustrating inter-relationships between solutions

The arrows labelled 1-7 indicate the non-linear back and forth movement between the different solutions which cannot adequately be described by words alone. For example, arrows 4, 5 and 6 illustrate how Tsebo used the relationship between the answer to 1 (b) and terms in the sequence which in turn was used to find the solution to question 2. The answer to question 2 was then related to the sequence which was used to find the solution to question 3. I provide details of how Tsebo “moved” between the solutions written on the chalkboard to make explicit how these questions were related to each other by his utterances, illustrated by a discussion of excerpt 1.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Utterances and gestures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T</td>
<td>If you put a 1 there (pointing to n in the general term formula) you get that number (pointing to the first term in the sequence written in the top left corner of the grid). If you put a 2 there (pointing to the n in the general term formula worked out in previous question), you get the second term. If you put a 3 there, you get the third term (arrow 3 in fig.2), ...... If you put 100 in there, you get the 100th term.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>---------</td>
</tr>
<tr>
<td>3</td>
<td></td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
<td></td>
<td>---------</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>So ..., find the 15th term? .... you put a 15 where the n is .... and it tells you, what the 15th term is (arrow 4 in fig. 2). So minus 4n plus 27 is the general term. Where there is n I put 15. ...... Negative 16 plus 27 is negative 33. This negative 33 is the 15th term. This means if we were to do this (pointing to terms in the sequence written in the top left corner of the grid) all the way to 15 (arrow 5 in fig.2), the 15th number would be negative 33.</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>---------</td>
</tr>
<tr>
<td>8</td>
<td>T</td>
<td>If we do this for two terms, the second term is 19, it means if we put a 2 in there (pointing to the n in the general term formula), we get 19 (pointing to the second term</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>---------</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>---------</td>
</tr>
</tbody>
</table>
Excerpt 1: Tsebo’s utterances illustrating relationships between questions

After finding the formula for the general term of the sequence, Tsebo mentioned that it was used to generate the sequence. He clarified that the phrase “used to generate the sequence” meant that if he substituted 1 for n it would produce 23 and continued this for the values 2 and 3 (lines 1-4). By using the values for n as 1, 2 and 3 he provided the opportunity for learners to see that the formula could be used to generate the sequence (arrow 3 in fig. 3). It also provided the basis for using the formula to find the 15\textsuperscript{th} term (the next question) i.e. if the values of 1,2 and 3 provided the first three terms then the 15\textsuperscript{th} term could be calculated by replacing n by 15 (lines 6-7). Having the solutions written close to each other helps in focusing the attention of learners on both the questions and the given sequence. The layout of the written work was accompanied by his utterances which “moved” between the three questions (and their solutions). He used the general term to show how the first three terms of the sequence could be found (arrow 3 in fig 3) and used the same idea to show how the 15\textsuperscript{th} term was found (arrow 4). He stated that if the sequence was continued to 15 terms (arrow 5) then the 15\textsuperscript{th} term would be -33. This answer of -33 as the 15\textsuperscript{th} term was used to illustrate its salience to the sequence (lines 8-10).
I propose that the close proximity of the solutions is intended to suggest the inter-relationships between the questions but on its own is probably insufficient to bring this into learners’ awareness. His utterances are accompanied by the layout of the written work to make these inter-relationships explicit. What connected the verbal with the written were his gestures which consisted of pointing to the relevant number/letter. When he said, for example, “if you put a 1 in there” (line 1), he also pointed to the n in the formula for the general term. When he said “you get that number” (lines 1-2) he pointed to term 1.

His utterances continued to revolve around how the solutions were written on the board by moving back and forth between the solutions to questions 2 and 3 and the given sequence. Having the solutions arranged one below the other suggests an intention to focus learners’ attention on both the solutions together. His utterances indicated that he also focused attention on both together drawing relationships between them as well as to the sequence. He used the answer to the question on finding the 15th term and related it to the next question (which term is -53? arrow 6). He asked learners which terms in the sequence (written above all four questions), were 23, 19 and 15 (lines 17-21), drawing attention to how the question related to the given sequence. He used learners’ answers (1st, 2nd and 3rd) to then ask “which term is -33?” Having the questions arranged one below the other with the sequence written above draws attention to the value of term 15 being -33 and how this relates to the sequence. He thus “moved” from question 2 to the sequence and back to question 3 (arrows 3 and 4). This “movement” between them highlights that the next question was the converse of the previous question i.e. the value of the term is now given requiring the position of the term. This was made explicit by Tsebo’s utterances. After illustrating the solution on the board, he reinforced the difference between the position and value of a term when he asked learners what the 20th term was (the answer to which term was -53) while pointing to the sequence (arrow 7) provided above the questions. The proximity of the questions were accompanied by his utterances moving between the answer to the second question, how it related to the third question and how these solutions related to the given sequence.

Tsebo’s explanation throughout this episode illustrates his use of the close physical arrangement to move seamlessly between all the questions making explicit the relationships between them. Finding that the terms of the sequence had a common difference led to using the appropriate formula to find \( T_n \). He then showed how the formula could be used to generate the given terms of the sequence and used the same idea to find the 15th term. He used the answer to this question to demonstrate how the next question (which term is -53) could be answered. Again what was being explained was the relationship between the questions.

The layout itself is static and does not communicate anything besides the solutions to the questions. The utterances of the teacher on their own also do not communicate the inter-relationships between the solutions. The layout of the written work on the chalkboard therefore “comes to life” through the teacher’s utterances. He used gestures to connect between both the verbal and the written forms. His verbal utterances complemented the physical layout of the solutions on the board by shifting between the metaphorical space between them. His verbal utterances involved shifting back and forth between the solutions and the given sequence to offer an explanation with a spatial component.
Example 2: Explanation with a spatial component to illuminate differences between contrasting examples

This example illustrates an explanation with a spatial component for the purpose of attending to the different strategies used in solving two contrasting examples. Placing contrasting examples next to each other on the chalkboard helps focus learner attention on these in a way that may not happen had the examples been written on different parts of the board or with other examples written between them.

The episode reported here was part of the third lesson on solving quadratic equations by factorisation. Ndivho (pseudonym) had illustrated to learners (in lesson 1) how to solve examples of the form \((x - a)(x - b) = 0\) using the zero product law. In lesson 3, he provided a range of examples in different forms including \((x - 7)(x - 5) = 3\). A learner provided the correct solution to this equation which Ndivho wrote on the chalkboard, to the right of which he provided an alternate first step to the solution and below which he wrote the example \((x - 7)(x - 5) = 0\) as shown in the picture of the boardwork in fig. 4.

![Fig. 4: Picture of contrasting examples](image)

Placing the contrasting examples next to each other can draw the attention of the learners to their differences. Ndivho’s verbal utterances made their differences explicit. Fig 5 indicates how he “moved” between the two examples.

![Fig. 5: Diagram illustrating differences between contrasting examples](image)
He asked learners how they would solve the second example i.e. \((x - 7)(x - 5) = 0\) (arrow 2 in fig.5). The excerpt below illustrates Ndívho’s verbal utterances in distinguishing between the two solution strategies.

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Utterances and gestures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T</td>
<td>Instead of 3 we now have zero, can we solve for (x) here? (arrow 1 in fig.4)</td>
</tr>
<tr>
<td>2</td>
<td>L1</td>
<td>(x) minus 7 is equal to zero.</td>
</tr>
<tr>
<td>3</td>
<td>T</td>
<td>(repeats).</td>
</tr>
<tr>
<td>4</td>
<td>L’s</td>
<td>Or (x) minus 5 is equal to zero.</td>
</tr>
<tr>
<td>5</td>
<td>T</td>
<td>(repeats). Do you see the difference here?</td>
</tr>
<tr>
<td>6</td>
<td>L’s</td>
<td>Yes.</td>
</tr>
<tr>
<td>7</td>
<td>T</td>
<td>Why don’t we say here (pointing to first example), (x) minus 7 equals to 3? Or (x) minus 5 equals to 3? …… (while writing this on the board)? (arrow 2 in fig. 4) Why in this case, why don’t we say, we do this (pointing to what he had just written)? Why don’t we do that? (arrows 3 and 4 in fig. 4) But here (pointing to the 2nd example) we say we can just say, it is either this is zero, or this is zero? Why is that so?</td>
</tr>
<tr>
<td>8</td>
<td>T</td>
<td>Learners are silent</td>
</tr>
<tr>
<td>9</td>
<td>T</td>
<td>It is because when we multiply two things and the answer is zero, it means one of those two is a zero? It is either the first one is zero or the second is zero (pointing to the factors in the 2nd example) but in this case we cannot say this equals to three or this equals to 3 because we need the side to be zero….. we can only do that if the other side is zero.</td>
</tr>
</tbody>
</table>

Excerpt 2: Utterances relating to differences between contrasting examples

Ndívho used the close proximity of the two equations to draw learners’ attention to the differences between them when he pointed to each (arrow 1) and said “instead of 3 we now have 0” (line 1). Lines 7 to 11 indicate his “movement” between the two examples to draw attention to the different solution strategies for each. He pointed to the first example i.e. \((x - 7)(x - 5) = 3\) and asked why they couldn’t solve by equating each factor to three (arrows 3 and 4) like they did with the second example indicating his movement between the two examples (arrow 5). His utterances were accompanied by his pointing to the relevant examples i.e. to the first example then to the factors in the second. In lines 12-15, he attempted to draw attention to why their solutions differed by saying that each factor can equal to 0 only when two numbers (“things”) are multiplied to give 0. He then referred to the first example again and said that in this case the right-hand side was three unlike in the second example where the right-hand side (pointing to the right-hand side of the second equation) was zero.

This episode illustrates an example of an explanation with a spatial component where Ndívho drew attention to the differences between the right-hand sides of both equations by his utterances together with his gestures thus “moving” between the two. He then focused on explaining their different solution strategies by again moving from one to the other verbally as well as by pointing to the relevant equation while talking. This illustrates an explanation that is not merely linear but flows back and forth between the physical space of the written examples and the metaphorical space between the verbal and written.

**Discussion**

The existing literature on instructional explanations does not address the possibility that an explanation may consist of both verbal and written forms. The two examples discussed above
show the importance of linking between the verbal and written forms. The insights provided by the explanations with a spatial component show that such explanations provide a teacher with the opportunity to move back and forth (both physically and metaphorically) between written and verbal forms to indicate the inter-relationships between different aspects such as sub-questions or alternate approaches.

Seminal work on instructional explanations by Leinhardt (2001) indicates the need to make links between different mathematical ideas. I have provided examples of explanations with a spatial component to illustrate how this is enacted in the classroom. An explanation with a spatial component is a possible response to the call by Mhlolo (2012) to support South African teachers in offering explanations that link different mathematical ideas. In the first example, I have shown how a teacher moves between the physical and metaphorical space between the examples written on the board and his utterances to show how the different questions on a given sequence are inter-related and how they link to the sequence. In the second example, I have shown how the close proximity of contrasting examples on the chalkboard can illuminate the different ways of working with each.

**Limitations**

In this paper, I do not focus on the quality of the teachers’ explanations. For example, Ndivho’s explanation is limited in terms of mathematical content. He could have illustrated that there would be more than one set of possible factors of 12, for example, and therefore a product equated to 12 could not be solved in the same way as when the product is zero. Investigating the quality of explanations is a focus in the ongoing larger study. A second limitation is the silence on how learners attend to the explanations. The focus of this paper is on teachers’ explanations. I therefore focused on how teachers make available some mathematical ideas to learners and not on what learners attend to.

**Conclusion**

I have provided an elaboration of instructional explanations by illuminating a spatial component using two examples. I illustrated how teachers’ use the close proximity of examples accompanied by their utterances to physically (by means of gestures) and metaphorically move between them to illuminate a mathematical idea. More importantly, the examples provide insight into explanations that are non-linear; they involve a back and forth movement between the space of the verbal and written forms. The attention to spatial components of explanations contributes to the theory on the nature of instructional explanations.

**References**


A MULTIPLICATIVE REASONING INTERVENTION IN GRADE 2
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Abstract

This paper reports on findings from a study focused on developing early multiplicative skills in a context of widespread low learner attainment in number. This study sought to understand the impact of intervention, focused around four carefully constructed lessons, that aimed to improve outcomes in multiplicative reasoning (MR) through attention to supporting learners’ construction of models. Positive learning gains achieved in a previous iteration of the study in another province provided the rationale for this study. Learner pre- and post-test data around the relatively short intervention show improved performance in terms of mean scores. Another important outcome is that this improvement in performance is associated with much greater inclusion of models of various sorts in learner responses in the post-test. This is an important finding in any context of highly inequitable learning outcomes coupled with ‘lags’ in number learning on the ground where not much attention has been given to learners’ construction of models as a means to developing their mathematizing capacity.

Introduction

Comparative assessments at national (DBE, 2012, 2013), regional (Chetty et al., 2017) and international levels (Reddy et al., 2016) paint a bleak picture of South African learners’ performance in primary mathematics, despite the recent improvements detailed in the SACMEQ IV study. Different bodies of research have reported on factors that contribute to the current state of education in South Africa, like learners’ rudimentary calculating strategies based on counting-in-ones well into upper primary grades (Schollar, 2008). Various diagnostic reports emanating from Annual National Assessments (DBE, 2012, 2013) suggest that South African learners struggle with word problems and situations that call for multiplicative reasoning. Within this context of primary education in ‘crisis’, an intervention study which sought to improve learning outcomes in multiplicative reasoning (MR) through attention to supporting learners’ construction of models when solving word problems was undertaken under the auspices of the Wits Maths Connect-Primary project.

In this study multiplicative reasoning (MR) is viewed as a ‘conceptual field’ (Askew et al., 2019) that involves multiplication and division which are seen as inter-related concepts. Multiplication and division have been described in literature as being problematic from a teaching and learning perspective (Lamon, 2005). The predictable manner in which mathematics concepts are sequenced in many curricula stems from the erroneous belief that additive reasoning (AR), which comprises the inverse concepts of addition and subtraction, is easier to grasp than MR. The failure to recognise the inter-relatedness of multiplication and division (as well as addition and subtraction) have resulted in these concepts being taught and learnt in staccato fashion which negates sense-making. Despite this limiting view, which results
in young children being exposed to multiplicative contexts much later than additive contexts, multiplication and division are considered key elements of mathematics teaching and learning.

Together with multiplicative reasoning, another important aspect related to the reported study is models and modelling. Researchers have described models in various ways: as an image that is ‘acted upon’ and that ‘stands-in-for’ something else (Askew, 2012) and as a representation that learners use to represent a problem or situation (Van den Heuvel-Panhuizen, 2003). Modelling is described in the literature as a process through which a real situation is simplified, structured and made precise by the ‘problem solver’ according to their various interests (Nesher, Hershkovitz & Novotna, 2003). Models and modelling are important in mathematics education because they are believed to assist both the teaching and learning of abstract, mathematical ideas that are often difficult for children to grasp.

**Background to the study**

These literature-based recommendations underpinned an intervention study that focussed on improving MR in the Foundation Phase through supporting learners’ construction of models. This work – led by the Wits Maths Connect-Primary (WMC-P) project – ran across 8 weeks during the first school term in 2020 (February to March) with 16 Foundation Phase-Mathematics Subject Advisors (FP-MSAs). Subject Advisors were required to implement a MR intervention with 2 or 3 Grade 2 classes from one willing school (quintile 1-4) in their respective districts. The context of this study was 35 Grade 2 classes from 15 primary schools in the North West Province (NWP) who served previously disadvantaged learner populations. A ‘pre-test – intervention – post-test’ design was used to determine the impact of this study which was the second iteration of a study conducted in the Gauteng Province in 2019. This study, which was focused around four carefully designed lessons, aimed to understand the possibilities for improved learner performance in MR through an intervention led by FP-MSAs who had minimal guidance from the WMC-P research team. The impetus for this study in the NWP was the positive learning gains produced by the first iteration of the study conducted with FP-MSAs from the Gauteng Province who had extended contact with the research team. Subject Advisors are seen as ‘the immediate arm of government that is closer to schools’ (Van den Berg et al., 2011). Thus, they are best placed to perform the mediating role that connects curriculum, classroom instruction and assessment.

**What is multiplicative reasoning (MR) and why is it important?**

MR is considered to be an important foundation in mathematics because it underpins different aspects of further number working which include ratio, proportion, fractions, Cartesian products and percentage. When entering formal education young learners encounter four main categories of practical situations that involve multiplication of whole numbers, which Greer (1992) identifies as:

- equivalent groups (e.g. Katlego has 4 bags with 5 apples in each bag. How many apples does he have altogether?)
- multiplicative comparison (*scale factor*) (e.g. Tom has 4 marbles and Sam has 5 times as many marbles as Tom. How many marbles does Sam have?)
• rectangular arrays (e.g. Monty planted 4 rows of apple seeds with 5 seeds in each row. How many apple seeds did Monty plant altogether?)
• Cartesian products (e.g. How many different sandwiches can Matt make with 4 types of bread and five toppings?)

These categories or ‘semantic structures’ that define different types of multiplicative situations evoke different solution strategies and vary widely in the level of difficulty (Vergnaud, 1983). In the examples given above the Cartesian product problem has shown to be more difficult for learners to solve than the other mathematically equivalent problems. Every multiplication situation can lead to various division problems. Equivalent groups division problems have been categorised as either partition or sharing problems and quotation or measurement/grouping problems. In sharing situations, the number in each group is not known, while in grouping situations the unknown is the number of groups. This distinction between semantic structures in division problems is important because this “is reflected in the modelling and counting strategies that children use to solve the problem” (Carpenter et al., 1999, p.34).

The distinct difference between MR and AR as conceptual fields, are noted by various authors (Verganud, 1983; Clarke & Kamii, 1996). Vergnaud (1993) highlights the difference between additive and multiplicative problems by noting the ternary nature of additive situations (these involve 3 numbers) and the quaternary nature of multiplicative situations (which involve 4 numbers). In a multiplicative problem like, ‘Ted has 5 boxes and puts 6 eggs in each box. How many eggs are there altogether?’ the fourth ‘hidden’ number is 1, which is implicit in the phrase ‘each box’. The subtle ratio invoked in multiplicative problems, are what makes them so distinct from additive problems (Askew et al., 2019). This distinction between MR and AR is the basis for Greer’s (1992) argument against merely seeing multiplication as repeated addition and division as repeated subtraction, as these are very limiting views of complex situations.

As previously noted, the strategies learners use to solve problems are influenced by the semantic structure of the problems. Carpenter et al. (1999) describe young learners’ initial attempts at solving multiplication and division problems as a ‘direct modelling’ of the actions and relationships depicted in the problem. These direct models usually involve reconstructions of the situation using concrete manipulatives such as counters. Mulligan and Mitchelmore’s (1997) work suggest that young children’s strategies for solving one-step, whole number multiplicative word problems are: “direct counting, rhythmic counting, skip counting, additive calculation and multiplicative calculation” (p.311). However, learners’ solution strategies are not in focus in this paper as these calculation strategies cannot be reliably inferred from the models evident in learners’ inscriptions (which constitutes the corpus of my data). I now focus on models in the context of multiplicative problems.

**What role do models play in multiplicative reasoning?**

A model can be defined as a representation that learners use to represent a problem or situation (Van den Heuvel-Panhuizen, 2003). Models can be internal images evoked as learners think about mathematical ideas or external inscriptions like written symbols, pictures or physical objects (Harries & Barnby, 2007). Models are important for developing multiplicative thinking as they are often used to ‘concretize’ abstract mathematical ideas in ways that make
it easier for learners to grasp (Gravemeijer, 1999). When problem solving, models can help clarify ideas in ways that support learners’ reasoning and build understanding (Kilpatrick et al., 2001). Examples of models’ learners use to represent multiplicative problems include: an array (links to area model), a double number bar, and a table model.

Drawing on Mulligan and Mitchelmore’s (1997) work, I now discuss young learners’ intuitive models for solving multiplicative problems. Such intuitive models are of interest because they can have a negative effect on later learning of more complex multiplicative situations. These intuitive models, which are related to the semantic structure of word problems, may develop over time into more formal models and this progression is linked to increased learner performance. The model learners call into play when solving a particular problem depends on several factors. Two of these factors pertinent to my study are: learners’ previous experience of and instruction in that problem situation and learners’ knowledge of the relevant number facts involved in the problem (Mulligan & Mitchelmore, 1997). Drawing on these factors, the design of the intervention being reported on purposely built in practice with multiplication number facts linked to the problems in the lessons. The selected teacher examples and practice questions for each lesson provided learners with instruction in and experience with one particular multiplicative situation – which was further highlighted in class discussions through questions like ‘What was the same/different between the problems?’ The intervention underpinning this study aimed to support learners’ construction of the array model to clarify the problem situation and encourage sense-making.

**Arrays**

The array model consists of rows and columns which indicate the different input values in a multiplication problem. Figures 1 and 2 below show array models for $5 \times 3$ and $3 \times 5$, respectively – the first factor in the number sentence shows the number of rows/groups and the second shows the number in each row/group. Once learners grasp the commutativity of multiplication ($a \times b = b \times a$) then this distinction is less important.

$$5 \times 3 = 15$$

Figure 1.

$$3 \times 5 = 15$$

Figure 2

Drawing mainly on the body of work by Barmby et al., (2009) I now highlight some of the positive attributes of the array model. The two-dimensional orientation of the array connects strongly with the corresponding multiplication number sentence: number of rows multiplied by number in each row (i.e. number of columns) – where the total number of items represents...
the product. The array can thus be seen to make the binary nature of multiplication visible (Anghileri, 2000), with the rows and columns representing the two distinct inputs. Because the two input values and the product in a multiplication sentence is made visible in an array model (e.g. $5 \times 3 = 15$ in Fig.1), the same model can be used to show a linked division number sentence (e.g. $15 \div 3 = 5$). Thus the array can be used to make the link between multiplication and division clearer to learners. This model can also help learners move from an ‘operational conception’ of multiplication and division – where these operations are viewed in terms of processes or actions – to a more ‘structural conception’ that allows learners to see these operations “at a glance” as if they were static objects (Sfard, 1991, p.29).

The arrangement of rows and columns in an array sets up the idea of a ratio, which is what makes multiplicative situations so distinct from additive situations (Askew et al., 2019). In Fig.3 the ratio depicted by the array model is 1 row: 6 dots or 1 to 6. This array could be used to model/solve the word problem: *Mr Nkosi planted 8 rows of mielies with 6 mielies in each row. How many mielies did Mr Nkosi plant altogether?* The numbers on either side of the rows can be read as ratio pairs: ‘One row six mielies, two rows twelve mielies, three rows eighteen mielies’, etc. The next step would be for learners to represent these pairs on a double number bar – a more formal horizontal model – that shows how the number of rows and the number of mielies covary together through the inclusion of all possible ratio pairs. Following on from the double number bar, learners could then record ratio pairs in a T-table (or ratio table) which allows for the covarying values to be recorded in a truncated manner. For example, in Fig.3 the T-table shows how doubling generates the solution to the word problem above in 4 entries, while twice as many entries are needed on the double number bar to obtain the same solution. The array thus also acts as a bridge to more formal, symbolic models like the double number bar and the T-table which literature describes as very useful for highlighting multiplicative relationships (Askew et al., 2019). The array model was foregrounded for MR intervention at the Grade 2 level because of its ability to explicate important multiplicative characteristics (like commutativity) and for its affordances concerning progression to more formal models.

![Figure 3](image-url)
Theoretical bases

The body of work emanating from the Realistic Mathematics Education (RME) camp is based on the premise that learning outcomes can improve through attention to learners’ mathematizing capacity, and particularly, learners’ capacity to construct and refine models of situations (Van den Heuvel-Panhuizen, 2003). This premise underpins the rationale for the intervention in the NWP that was designed to support learners’ construction of the array model as a means of improving MR learning outcomes. Whilst the RME tradition is opposed to teachers’ imposing ready-made models on learners, the notion of teachers playing a supportive role in helping learners construct and interpret models (Barmby, Bolden, Raine & Thompson, 2013) was writ large in this intervention. This is because of the inadequate development of symbolic representations and models that is suggested as a contributing factor for poor performance in mathematics through the Intermediate Phase (Venkat, 2013, p.32).

Within RME, children’s intuitive models are referred to as ‘emergent’ models because they are grounded in the way the contextual situation in the problem is understood and structured by children. Emergent models are informal models that function as base inventions for more formal models, thereby making allowance for the process of ‘progressive mathematization’ (Gravemeijer, 1994b) which promotes progression from informal to formal models. Emergent modelling refers to the model which emerges in the process of structuring the problem situation as part of the ‘organizing’ activity (Gravemeijer & Stephan, 2002). Initially, models of situations are often context-specific in their depiction of a meaningful problem situation that is experientially real for the learner – it is a ‘model of’ that situation. Then, through working with this model, the model gradually acquires a more generic character and develops into a ‘model for’ mathematical reasoning.

Learners’ emergent models are often less sophisticated and more informal than ‘didactical’ models such as the bar model and double number line (Klein, Beishuizen, & Treffers, 1998). Some examples of less sophisticated emergent models as described by Carpenter et al. (1999) are physical counter arrangements, scribbles and drawings. Carpenter et al. (1999) use the phrase ‘direct models’ to describe the kinds of models that children initially devise which involve concrete reconstructions of the situation using manipulatives. These emergent models often do not reflect more compressed mathematical structure, reasoning and generalisation because of their concrete nature.

RME’s emphasis on using ‘realistic’ problem situations to develop learners’ mathematizing capacity through greater sense-making was also taken into account in the selection of multiplicative problems used in intervention lessons. Evidence on the ground that flags the disconnected nature of early grades lessons in some South African schools prompted the inclusion of class discussion in each lesson where teacher and learners talk about the structural similarities between problems. Taken together, the literature in the field and the context on the ground led to the following research question: What differences (if any) are evident in learner models present in post-test scripts compared to pre-test scripts that show learners’ working on Multiplicative Reasoning (MR) tasks?
Research design

The second iteration of the MR intervention, which was conducted in the NWP, sought to upskill FP-MSAs to be better able to facilitate curriculum delivery in a way that improves mathematics teaching and learning in the classroom. The project consisted of an initial training session run by WMC-P project in Rustenburg and a four-lesson intervention sequence run by FP-MSAs in a local school. The WMC-P team developed the training and intervention materials and collaborated with North West FP-MSAs to translate these into Setswana. FP-MSAs negotiated access to schools with principals and two or three Grade 2 teachers willing to participate with their classes in the MR intervention consisting of a pre-test, four intervention lessons run one lesson per week in Term 1 (February-March, 2020), and a repeat sitting of the test as a post-test. This short study was intentionally designed to fit easily into classroom practice in ways that did not disrupt teachers’ current work. Each FP-MSA then worked with their participating teachers on discussing the materials, and translating them into classroom teaching with in-class support. The FP-MSAs also administered, marked and captured learner responses to the pre- and post-tests across participating classes. As part of the collaboration, the FP-MSAs then sent the final spreadsheets with captured responses to me, and collected in the learner scripts for me to keep as a way of checking the marking, and looking subsequently at learners’ written approaches to particular sets of items in the tests.

Intervention Model:

- An initial workshop held with all participating FP-MSAs. The focus was on the foundations of multiplication and division working, and the teaching models, tests and materials to use in the 4-lesson intervention sequence. Every Subject Advisor received teaching and learning materials for every teacher and class.

- FP-MSAs worked with 2 or 3 Grade 2 teachers in a school in their district. This work involved: meeting with the teachers to explain the intervention model and timelines; working with teachers to administer, mark and collate results of the pre-tests; setting up two planning, support and reflection meetings with the teachers; and observing and supporting the teaching of two intervention lessons. Pre-test results for each class were captured on spreadsheets and emailed to me.

- A mid-reflection workshop was held with all participating FP-MSAs mid-way through the project to reflect on the intervention process and provide support where needed. Hard copies of learner pre-test scripts were submitted to me.

- FP-MSAs oversaw the teaching of the final intervention lessons and conducted the post-test with participating Grade 2 classes. Post-test results for each class were captured on spreadsheets and emailed to me. The unforeseen national state of emergency brought about by the COVID-19 pandemic interrupted this process. Fifteen of the 16 Subject Advisors were able to capture and email their respective classes’ post-test results in the weeks following the lockdown. Hard copies of learner post-test scripts were either posted to WMC-P or collected by a courier.
- A post-intervention reflection workshop with FP-MSAs was planned for but did not take place due to the COVID lockdown. The intended focus for this session was to reflect on how the work with teachers went, what gains (if any) were achieved by learners, and the possibilities and challenges of working more directly and responsively on supporting primary mathematics teaching.

- A post-intervention reflection form was subsequently emailed to FP-MSAs to get a sense of their experiences during intervention. The feedback received will feed into upcoming intervention cycles in 2021 and 2022.

The test administered prior to and immediately following intervention took the literature-based suggestions regarding various semantic structures (and their levels of difficulty) of multiplicative situations into account. The test had 14 items, 10 items focused on multiplication/division (the focus of the intervention) and 4 items focused on addition/subtraction that were interspersed between MR items. The inclusion of AR items was used strategically so that learners were not cued in to solving every task with either a multiplication or division operation. The tasks were mostly contextual/word problems and a few were number-based tasks. Given the extent of ‘lags’ between the specified curriculum content and learner performance (DBE, 2012, 2013, 2014) all test items were read at least twice by the FP-MSA who conducted each test. Test items were repeated where needed and learners were given 2-3 min to answer each question.

**Broader findings for the larger study**

We obtained matched pre- and post-test data from 15 Subject Advisors for 1458 learners, from 35 Grade 2 classes, across 15 schools in the NWP who participated in the intervention. Table 1 below shows the mean percentage for pre- and post-test learner performance for all 14 test items; and it also shows the mean percentage for the MR items only (10 items). The third column shows the mean gains for each which are presented as percentage points (pp).

<table>
<thead>
<tr>
<th>Overall Mean Percentage (14 items)</th>
<th>Pre-Test</th>
<th>Post-Test</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%</td>
<td>43%</td>
<td>+ 18pp</td>
<td></td>
</tr>
<tr>
<td>MR Mean Percentage (10 items)</td>
<td>22,8%</td>
<td>40,3%</td>
<td>+ 17,5pp</td>
</tr>
</tbody>
</table>

Pre-test results indicate that learners in the NWP started the intervention from a very low-base (overall mean 25% and MR mean 22,8%) which is indicative of the widespread low-attainment across South African schools, and particularly in the NWP, reported on in local and regional literature (Chetty et al., 2017). The overall post-test mean score was 43% while the post-test mean for MR was 40,3%. This indicates an increase of 18pp on the overall mean and 17,5pp for the MR mean. The learning gains achieved by this cohort of Grade 2 learners are commendable on the back of a very short intervention sequence (i.e. 4 lessons) at the time of the year when multiplication and division had not yet been covered in class. Greater detail on the quantitative analysis of the broader study is expounded on in a Masters study based on this work, which is not shared here. However, it is important for me to highlight the broader study
as this provides the backdrop for the particular analysis carried out in support of my interest in learner models.

Next, I present data and related analysis for Malima Primary School (anonymised) – one of the 15 government schools that participated in the broader study in the NWP. This school was of interest to me as learner performance was indicative of the performance seen across other schools in the sample.

**Findings, Analysis and Discussion**

Three Grade 2 classes at Malima Primary School participated in the MR intervention. We obtained matched pre- and post-test data for 140 learners and this formed the corpus of my data. Learner results are presented as one group for ease of reading.

**Learner performance on multiplicative reasoning items**

Table 1 below shows the number of correct responses on multiplicative reasoning items in the pre- and post-test that topped and tailed intervention. A positive difference between the number of correct answers across pre- and post-tests are considered learning gains while the opposite holds true for a negative difference.

**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q7</th>
<th>Q8</th>
<th>Q9</th>
<th>Q10</th>
<th>Q13</th>
<th>Q14</th>
<th>TOTALS</th>
<th>Mean Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>POT</td>
<td>CAB</td>
<td>SWT</td>
<td>CNT</td>
<td>BAG</td>
<td>POT</td>
<td>PIE</td>
<td>EGG</td>
<td>POT</td>
<td>PIE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 x 3</td>
<td>6 x 4</td>
<td>30 ÷ 3</td>
<td>40 ÷ 5</td>
<td>3 x 8</td>
<td>24 ÷ 4</td>
<td>8 x 5</td>
<td>30 ÷ 6</td>
<td>5 x 3</td>
<td>24 ÷ 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n=140</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRE-TEST</td>
<td>92</td>
<td>26</td>
<td>96</td>
<td>14</td>
<td>42</td>
<td>4</td>
<td>1</td>
<td>38</td>
<td>62</td>
<td>20</td>
<td>395</td>
<td>28.2</td>
</tr>
<tr>
<td>POST-TEST</td>
<td>116</td>
<td>86</td>
<td>63</td>
<td>10</td>
<td>95</td>
<td>35</td>
<td>49</td>
<td>68</td>
<td>85</td>
<td>41</td>
<td>648</td>
<td>46.2</td>
</tr>
<tr>
<td>gains</td>
<td>24</td>
<td>60</td>
<td>-33</td>
<td>-4</td>
<td>53</td>
<td>31</td>
<td>48</td>
<td>30</td>
<td>23</td>
<td>21</td>
<td>253</td>
<td>18pp</td>
</tr>
</tbody>
</table>

Table 1 shows that in the pre-test Q4 (a word problem with 30 ÷ 3 as the calculation) had the most correct responses (96) followed closely by Q2 (word problem: 5 × 3) with 92 correct. In the post-test Q2 (word problem: 5 × 3) had the highest performance (116) followed by Q7 (word problem: 3 × 8) with 95 correct responses. The biggest gains were made in Q3 (word problem: 6 × 4) and Q7 (word problem: 3 × 8) while Q4 (word problem: 30 ÷ 3) had the biggest regression across pre- and post-test results. Overall, there were 45 more correct responses to division tasks (Q4, Q5, Q8, Q10 and Q14) in the post-test compared to the pre-test and 208 more correct responses to multiplication tasks (Q2, Q3, Q7, Q9 and Q13) in the post-test.

**Exemplification of models present in learner scripts**

What follows are examples of how learner models from pre- and post-test scripts were coded:
A. Picture A is taken from the post-test script of L2 in 2B. This is an example of a learner model that was coded as *structured tallies* because the structure of 3s is evident through the use of spacing.

B. Picture B is another example of a learner model coded as *structured tallies*. Here structure is evident in the circles drawn around every 3 tallies. Taken from the post-test script of L8 in 2A.

C. Picture C is an example of a model coded as an *array*. The spatial arrangement and the use of an equal number of rows and columns is what makes it an array. Taken from pre-test script of L40 in 2B.

D. In Picture D we see iconic drawings of apples (the context of the word problem) in equal rows and columns. This model is also coded as an *array* (not as iconic) because of the spatial arrangement. Taken from L19 in 2B post-test.

E. Picture E is taken from L7 in 2B’s post-test script. This is an example of a model coded as *deleted tallies*. The learner drew 25 tallies, deleted 18 and counted what was left as the answer. Learners often use this model for subtraction as ‘take’.

F. Picture F is also taken from L7 in 2B. This model is coded as *unstructured tallies* because the learner drew 24 tallies without showing any structure and with no tallies deleted.

G. Picture G is an example of an *iconic* learner model because the drawings resemble the real-life image of 5 cartons of 6 eggs. This is taken from the post-test script of L51 in 2A.

H. In Picture H we see no model with only the correct answer written. This is coded as *no representation with correct answer*. Other instances when learners used no representation were either accompanied by no answer or an incorrect answer. L1 2C pre-test.

Tables 2 and 3 show the number of models present in learners’ pre- and post-test scripts respectively. The columns and rows in each table show the frequency of different models present per task and the frequency of particular models present across all ten multiplicative tasks. Learner models were tallied whether the accompanying response was correct or not. The first three rows show the number of instances when no model was evident with either a correct answer, incorrect answer or no answer.
Table 2 shows four types of learner models present in the pre-test namely, *structured tallies* (TS), *unstructured tallies* (TU), *iconic drawings* (ICON) and *arrays* (A). Table 3 shows five models present in the post-test which includes all models present in the pre-test as well as *deleted tallies* (TD). The most common learner response in the pre-test was *no representation* with an incorrect answer (47.3%), which was more frequent than all learner models combined (21.2%). There were 1202 instances of learner models present in the post-test – 904 more than in the pre-test – with *structured tallies* (48.7%) the most common amongst these. Overall, the learner cohort from Malima Primary omitted 139 MR tasks in the pre-test compared to 5 tasks omitted in the post-test.

The following points outline the differences evident in learner models across pre- and post-tests in light of learners’ working on multiplicative reasoning tasks:

- learners performed better on MR tasks in the post-test than in the pre-test,
- learners used more models to answer MR tasks in the post-test compared to the pre-test and
- learners omitted fewer MR tasks in the post-test than in the pre-test.

In the next section these points are discussed and interpreted in light of the literature reviewed.

**Conclusion**

The positive learning gains achieved across pre- and post-test scores show that a carefully structured, short intervention sequence focused on a particular mathematical concept can raise learner attainment on the ground. This outcome is a positive message in a context that is
plagued by historical inequalities in education and the resultant, skewed access gained to the market place (Spaull, 2013), that seem entrenched in the fabric of South African society despite various efforts to right the inequities of the past.

Post-test outcomes point to improved performance that is linked to wider evidence of models in learners’ post-test working and also to a decrease in the number of tasks that were not attempted. Whilst correlation cannot generally be taken as evidence of causation, the literature base discussed earlier note that models support learners’ reasoning, builds understanding and improves learning outcomes (Kilpatrick et al., 2001; Mulligan & Mitchelmore, 1997). One of the caveats suggested by this data set is that Grade 2 learners’ capacity for model construction appeared better in multiplication situations and improved performance was more evident in learner responses to multiplication problems.

The large number (i.e. 68.8%) of learner pre-test scripts that showed an absence of models, suggests a lack of capacity for this kind of model set-up. This validates the design decision to introduce a literature-based model – the array – that is linked to increased sense-making and improved performance in MR in a landscape where ‘random guessing’ (Hoadley, 2007), rudimentary strategies (Schollar, 2008) and low attainment (Chetty et al., 2017) are widespread. In the same vein, it is interesting to note that whilst the intervention was designed to foreground the array model in particular, the majority of models present in learner’s post-test working were structured tallies (48.7%). This outcome is not viewed in a negative light because Grade 2 learners’ use of mathematical structure is encouraging in light of earlier evidence that showed Grade 3 learners use of tallies with no evidence of structure (Ensor et al., 2009); this too in a context where widespread evidence of counting-in-ones persists into the Intermediate Phase (Schollar, 2008). This result, together with positive outcomes obtained with Grade 4 learners’ work with arrays (Malola, 2020), provides the research team with cause to look more closely at the design of the intervention for Grade 2 learners.

The positive outcomes from this project suggest that FP-MSAs can be supported to work constructively with teachers on the ground to improve learning outcomes with minimal input from the research team who designed the intervention and the materials. This finding is of importance in a context where the capacity of district personnel to support learning is increasingly being questioned.

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SELF-REGULATION STRATEGIES USED BY FEMALE STUDENT TEACHERS IN PRIMARY MATHEMATICS TEACHER EDUCATION

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University of Malawi

Abstract

We discuss findings from an exploration of self-regulation strategies used by female student teachers to enhance their learning of mathematics, and the support they require to boost the effectiveness of the strategies. Data was collected using mixed methods; 523 female students from six public teacher colleges completed a questionnaire, and 160 of them participated in focus group discussions. The quantitative data was analysed using descriptive statistics while the qualitative data was analysed using thematic analysis. The findings reveal that the most common self-regulation strategies used by the female student teachers are group discussions, individual practice and asking other students for assistance. The most needed forms of support are clear explanations by their lecturers, more time to practice solving mathematics problems and more books and internet access. We argue that increasing female participation in mathematics should go beyond increasing numbers of females into the teacher colleges by also including support for their self-regulation learning.

Keywords: self-regulation learning, female participation, female students, gender, Malawi, mathematics, primary teacher education.

Introduction

Years after the United Nations declaration and emphasis on Education for All, girls and women continue to be denied equal opportunities to education and participation in science, technology, engineering and mathematics (STEM) in most parts of Africa (Kizito, Munyakazi & Basuayi, 2016; Mandina, Mashingaidze & Mafuta, 2013; Yacoubi, 2015). For example, Naidoo and Kapofu (2020) and Kizito et al. (2016) report about low participation of females in mathematics in schools and in STEM related careers in South Africa. They attribute the problem of lack of females in the STEM careers to low numbers of female graduates in the STEM subjects at the tertiary level.

Unlike the developed countries where the gender gap in school mathematics and science is insignificant, in most of the Sub-Saharan African countries there are still gender gaps (Du Preez, 2018; Mandina et al., 2013). Malawi reports gender gaps in mathematics from as early as primary school level (Mbano & Nolan, 2017; Ministry of Education, Science and Technology [MoEST], 2014a). This implies that fewer girls than boys are accepted to merit based, higher quality secondary schools (MoEST, 2014a), and as a result, less than 30% of the females enroll for mathematics and science programs at tertiary level in Malawi (Mbano & Noran, 2017). This is worrisome because mathematics and science contribute to economic growth of both an individual and the country through provision of rewarding careers (MoEST, 2014a; Yacoubi, 2017). One of the strategies used by Malawi government to reduce the gender gap is training of more female primary school teachers who would act as role models to the primary school
girls (MoEST, 2014a, 2014b). In addition, there are some innovations to support females’ participation in mathematics and science in schools with the aim of increasing their access to tertiary mathematics and science (Forum for African Women Educationalists in Malawi, 2016). However, such support is not available at the primary teacher training colleges (TTCs). This implies that when enrolled into the TTCs, female student teachers need to adapt to their new environment by developing self-regulation strategies that would enable them learn mathematics successfully (Özyıdrım, Alkaş & Özdemir, 2011). We have not found any literature on studies about self-regulation strategies used by the TTC female student teachers to promote their learning of mathematics in Malawi. Therefore, the purpose of this study was to investigate self-regulation strategies used by TTC female student teachers in learning mathematics and the support they require to enhance the effectiveness of their self-regulation strategies.

**Malawian education system and primary teacher education**

Malawi has eight years of primary school and four years of secondary school. At the end of secondary school there is a national examination which awards a qualification called the Malawi Schools Certificate of Education (MSCE) to those that pass. The MSCE is used for entry into University and other tertiary education including primary teacher education. Primary teacher education in Malawi is offered by TTCs. There are 8 public TTCs spread across the country and they all follow the same curriculum and programme. Duration is two years divided into six terms; three terms per year and same as the school terms. The programme starts with two terms of college-based taught courses, followed by two terms of teaching practice in primary schools, then finally two terms of more college-based taught courses (MoEST, 2017). Entry qualification into the programme is MSCE with passes in mathematics and science. The pass in mathematics and science as entry requirement was introduced in 2016 in an attempt to improve the quality of primary school teachers. The requirement of a pass in mathematics is good because it ensures teachers that have good knowledge of school mathematics as they are required to teach all primary school subjects. Unfortunately, the requirement has led to low numbers of female students’ enrolment in the TTCs as compared to male students because many female applicants fall short of a pass in mathematics at MSCE. For example, in 2019 the total enrolment at six public TTCs that participated in this study was 771 (39%) females and 1220 (61%) males. The low female student enrolment at the TTCs contradicts the stated goals of the National Girls’ Education Strategy (MoEST, 2014b) of closing the gender gap in primary education by providing more female teachers to act as role models to girls in the primary schools. Furthermore, it might reduce female participation in the courses as the females might feel intimidated because they are outnumbered by male peers (Dasgupta & Stout, 2014).

**Literature Review**

Self-regulated strategies are tools used by an individual within his or her self-regulated learning (Zimmerman, 1990). Self-regulated learning is a process where an individual actively takes part in setting learning goals, monitors, manages and regulates actions to achieve the goal (Özyıdrım et al., 2011). Literature reveals that apart from student achievement and cognitive capacity, there are other non-intellectual factors that affect tertiary education students’
performance (Richardson, Abraham, & Bond, 2012). These include; personality traits, motivational factors, self-regulatory learning strategies, students’ approaches to learning, and psychosocial contextual influences. Among these non-intellectual factors, motivational factors and self-regulatory learning strategies correlate greatly with student performance. Özyıdrım et al. (2011) studied pre-service elementary mathematics teachers’ views on factors affecting their self-regulation strategies as they study courses related to mathematics education with pedagogical content. They found that the pre-service teachers’ choice of self-regulatory strategies are influenced by amount of time available for studying, requirements of the course, and the characteristics of the instructor such as attitude towards students and expectations from the students.

Wong and Lai (2006) investigated factors affecting mathematics teaching effectiveness among pre-service primary mathematics student teachers. They found that that Pedagogical Content Knowledge (PCK) is the crucial factor that leads to effective mathematics teaching. Furthermore, they also found that female student teachers taught better than male student teachers, and that female student teachers demonstrated more creative and well-designed instructional strategies than those by male student teachers. This implies that if given opportunities to develop their knowledge, female student teachers are capable of becoming effective mathematics teachers.

In Malawi studies on primary mathematics teacher education are few, we found only three that are relevant to this paper. The first was done by the Malawi Institute of Education [MIE], where they evaluated the instructional materials for teacher education programme from the perspectives of the TTCs lecturers. Their findings revealed that the instructional materials were inadequate; not all lecturers were competent in the curriculum; and there was minimal monitoring of the implementation of the curriculum in TTCs. The lecturers highlighted some specific issues regarding mathematics teacher education, including that there was lack of motivation among student teachers to learn mathematics and to become mathematics teachers. MIE (2008) lament that these issues limit the student teachers’ learning and eventually limit their teaching of mathematics in primary schools. The second, Jakobsen, Kazima and Kasoka (2018) examined whether the Malawian primary teacher education programme develops student teachers’ mathematical knowledge for teaching (MKT). They administered an MKT pre-test and post-test test to 1,700 student teachers from all eight public TTCs to measure their mathematical knowledge for teaching. They performed a paired sample t-test for 1223 student teachers’ pre-test and post-test scores and found that overall, there was significant improvement in the student teachers’ MKT, suggesting that the teacher education programme is effective. Further analysis of the individual TTCs revealed that there was no improvement in MKT of student teachers at one TTC, and there was variation in the amount of knowledge gain in the other TTCs (Jakobsen et al., 2018). This implies that teaching and learning varies across the colleges, and that at the one college the teaching and learning was not effective. It is likely that the student teachers that registered no improvement did not have effective self-regulatory strategies. The third study by Mwanza, Moyo and Maphosa (2016) focused on the school-based component of the teacher training programme and assessed the structures and processes of quality monitoring of mentoring of student teachers during teaching practice in schools. The results revealed that there were no set-up structures to monitor the practices of mentoring in
the primary schools. In addition, there were no standard guidelines in terms of what was to be monitored, the frequency of monitoring, and the approach to monitoring quality of mentoring. This implies that some student teachers do not receive enough support during the school-based training. Consequently, such student teachers mainly rely on the knowledge they acquire during college-based training to plan, implement and evaluate their lessons. Therefore, it is important to understand the student teachers’ self-regulation strategies for learning, which was the aim of this study. It was part of a larger study that investigated the participation of female student teachers in mathematics at TTCs. Findings from the larger study include that 68% of the female student teachers who participated in the study would choose to study mathematics were it optional while 32% would not, and that there is high correlation between the student teachers’ MSCE mathematics grade and their confidence in studying mathematics at TTC (Mwadzaangati & Kazima, 2020). The sample of female student teachers is the same as in this study.

Learning from the literature as discussed above, we take the position that self-regulation strategies are important in students learning. Our theoretical orientation is drawn from (Zimmerman, 1990) that successful learners are those that are able to use different self-regulated strategies to enhance their learning. Therefore, knowing students’ self-regulation strategies informs education institutions on how best to support their students’ learning.

Methodology

To gain an overall picture as well as in-depth insights of the female student teachers’ self-regulation strategies and the support they require, we employed a mixed method approach where we collected both quantitative and qualitative data (Cohen, Manion & Morrison, 2007). Quantitative data was collected by administering a survey questionnaire to the female student teachers. The aim was to collect quantifiable data that would enable us to produce statistical information on self-regulation strategies used by the female student teachers and the support required (Pallant, 2010). Qualitative methodology involved conducting focus group discussions (FGDs) with some of the female student teachers who completed the questionnaire to understand reasons behind their responses.

Sample and data collection

The target group was all female student teachers enrolled in six public TTCs in Malawi. The six public TTCs were purposefully selected using availability of female mathematics lecturers at the TTCs who were previously involved in professional development workshops funded by the project which also funded this study. Altogether, there were 771 female student teachers in the six TTCs and they were all given questionnaires to complete, and they were told that participation was voluntary (Cohen et al., 2007). A total of 523 female student teachers completed and returned the questionnaires, representing 68% response rate. The data was collected at a time when the students had covered about half of the taught courses. The questionnaire contained five questions; two of which were closed and three were open-ended questions. This paper report on findings from two open ended questions. The first question required the female student teachers to write down one self-regulation strategy that they frequently use and rely upon to improve their performance in mathematics education courses.
The second question required the female student teachers to write one type of support that they would need for their self-regulation strategy to be effective. After completing the questionnaire, a sample of the student teachers that volunteered were selected to participate in FGDs. The two questions were used as a guide during the FGDs. All together there were 20 FGDs conducted and the duration ranged from 40 to 60 minutes for each FGD. Each group had eight female student teachers that were grouped according to the strategies that they indicated. Both administering of the questionnaire and the FGDs were done by female lecturers who teach mathematics at the TTCs to enable the female student teachers feel at ease as the lecturers might have already established rapport and sense of security with them (Cohen et al., 2007).

**Data analysis**

Responses to the questionnaire were coded using numerical codes. Responses to the open-ended questions were read carefully to identify common themes and assign numerical codes to each theme. The questionnaire data was then captured in statistical package for the social sciences (SPSS) where the numerical codes of responses for each respondent were recorded as a separate entry (Pallant, 2010). Statistical analysis was conducted and simple descriptive statistics such as frequencies, percentages and cross-tabulations were obtained (Pallant, 2010). For the qualitative data from FGDs, thematic analysis was done using a priori-themes (Cohen et al., 2007) that were generated from the quantitative data.

**Results and discussions**

We first present the quantitative results and compare them with the qualitative results and the literature. We begin by presenting the results on self-regulation strategies that female student teachers use to enhance their learning of mathematics, followed by results on support required by the female student teachers.

**Self-regulation strategies used by the female student teachers.**

The findings reveal that female student teachers use different self-regulation strategies to enhance their learning of mathematics courses. Figure 1 shows the frequencies of the identified self-regulation strategies in descending order.
As can be seen from figure 1, the three most common self-regulation strategies used by the female student teachers to enhance their learning of mathematics courses are as follows: group discussions (39%), regular individual practice (29.6%), and asking fellow students (16.8%). The least commonly used self-regulation strategies are: consulting other books (3.8%), asking lecturers to assist (2.7%) and part-time classes (0.8%). Similar findings were also revealed by Eneya, Mwadzaangati and Kazima (2019) who studied coping strategies used by university undergraduate mathematics female students in Malawi to enhance their learning of mathematics. Eneya et al. (2019) found that the female mathematics students use the following strategies in descending order of frequency; practicing solving mathematics on their own, group discussions with fellow students and studying after class. Richardson et al. (2012) call group discussions as peer learning and describe it as a tendency to work with other students in order to facilitate one’s learning. It is surprising that there are very few female student teachers who ask their lecturers to assist them. It is however worrisome that 7.3% of the female students do not use any strategy to enhance their learning of mathematics as it might mean that they do not put any effort into their learning and their performance in mathematics might be decreasing. As Özyıldırım et al. (2011) argue, when individuals use self-regulation strategies, their academic success increases.

To find out if there was any relationship between the female student teachers’ MSCE mathematics grade and the type of self-regulation strategy used to enhance their learning of mathematics at TTC, cross tabulations were run between MSCE mathematics grade and the self-regulation strategies used. We firstly describe how the students performed in mathematics at MSCE in Table 1. The MSCE scores range from 1-9 where 1-2 is pass with distinction, 3-6 is pass with credit, 7-8 is bare pass and 9 is fail.
Table 1: Female student teachers’ grade at MSCE

<table>
<thead>
<tr>
<th>Mathematics Grade</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass with distinction</td>
<td>18</td>
<td>3.4</td>
</tr>
<tr>
<td>Pass with credit</td>
<td>308</td>
<td>58.9</td>
</tr>
<tr>
<td>Bare pass</td>
<td>197</td>
<td>37.7</td>
</tr>
<tr>
<td>Total</td>
<td>523</td>
<td>100</td>
</tr>
</tbody>
</table>

As shown in Table 1, out of the 523 female student teachers who participated in the study, 18 (3.4%) got distinction, 308 (58.9%) got credits and 197 (37.7%) got pass in mathematics at MSCE. The results of cross tabulations between students’ grades and the self-regulation strategies used are indicated in Figure 2.

Figure 2: cross tabulations between MSCE mathematics grade and self-regulation strategies

As it can be seen in Figure 2, the three most common self-regulation strategies used by female student teachers in each grade category are as follows in descending order; group discussions, regular individual practice and asking fellow students. There are no students from distinction grade category who do nothing to enhance their learning of mathematics. This agrees with Mwadzaangati and Kazima (2020) who found that the higher the student’s MSCE mathematics grade, the more the confidence to study mathematics. Figure 2 also reveals that there are no students in distinction category who do part-time classes. This seems to imply that due to their confidence in mathematics, students who get high mathematics grade at MSCE do not require extra classes.

Support needed by the female student teachers

The findings revealed that the female student teachers require several types of support for effective use of their self-regulation strategies. The frequencies of these are shown in Table 2.

Table 2: Support required by female student teachers

<table>
<thead>
<tr>
<th>Support required</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear explanation by lecturers</td>
<td>126</td>
<td>24.1</td>
</tr>
<tr>
<td>Provide time for practice</td>
<td>99</td>
<td>18.9</td>
</tr>
</tbody>
</table>
The results in Table 2 show that the most common support required by the female student teachers include: clear explanations by their lecturers (24.1%), more time for practice (18.9%), more books and ICT services (115.5%), more time for learning mathematics courses (11.1%), more support from their lecturers (8.8%), and more knowledgeable lecturers (7.1%).

The issue of provision of more learning resources like books and ICT services was also raised in Eneya et al. (2019). The support required by the female student teachers confirm MoEST (2020) which report that there are several challenges that affect the quality of teacher education in Malawi. These include: under-qualified TTC lecturers as most of them are secondary school teachers with limited primary education pedagogical skills, inadequate teaching and learning materials in the TTCs, poor performance management of student teachers and limited review of the TTC curriculum to enable improvements. This implies that these teacher education challenges limit the female student teachers’ ability to use their self-regulation strategies effectively to enhance their learning of mathematics.

To find out if the female student teachers’ mathematics MSCE grade would relate to the type of support needed by the female student teachers, cross tabulations were run between mathematics MSCE grade and support needed. The results of the cross tabulations are indicated in Figure 3.

![Figure 3: Cross tabulations between MSCE mathematics grade and support needed.](image-url)
The results in Figure 3 reveal several issues regarding students’ performance at MSCE and support required to enhance the effectiveness of their self-regulation strategies. Firstly, they reveal that some types of support mentioned by students who got credit and pass at MSCE were not mentioned by students who got distinction at MSCE. These include; provision of more time for learning mathematics and motivating mathematics lectures. This confirms that the higher the grade at MSCE, the more the students’ motivation to study college mathematics, hence they do not require to be motivated by their lecturers (Mwadzaangati & Kazima, 2020).

Secondly, the types of support that are highly required by students in the different performance categories are different to some extent. In the distinction category, the types of support required in high frequencies in descending order are: more support from the lecturers, clear explanations by the lecturers and provision of more knowledgeable lecturers. The types of support with high frequencies in the credit and pass categories are: clear explanations by the lecturers, provide time for practice, allocate mathematics courses more time for learning, and provision of more books and ICT services. The fact that support of provision of clear explanations by lecturers is required by students from all categories regardless of their MSCE mathematics grade suggest that the effectiveness of the students’ self-regulation strategies depend on how the lecturer explains the mathematical concepts in the classroom. Ball, Thames and Phelps (2008) argue that ability to make clear explanations depends on the teacher’s subject matter knowledge. This seems to suggest that some TTC lecturers are not able to explain mathematical concepts due to their challenge of content knowledge as reported by MoEST (2020) and justifies the students’ need for more support from their lecturers.

Findings from focus group discussions

The female student teachers raised several issues to elaborate on the different types of self-regulation strategies that they use and the support they need. As already noted, the female student teachers mostly prefer to use self-regulation strategies that either involve their peers or individually on their own, but not from their lecturers. Extracts 1 and 2 are examples of explanations given by the female student teachers regarding their preference of seeking help from fellow students than lecturers.

Extract 1

Other lecturers approach us in unfriendly manner such that sometimes we do not understand because we learn with fear. This makes us to be afraid to ask them when we do not understand. We therefore prefer to discuss in groups or to practice solving mathematics on our own than to go and ask lecturers. (College 3)

Extract 2

We fear to ask questions because of our lecturers’ mood, sometimes they do not answer us politely when we ask questions. So, we largely depend on our friends to help us during group discussion (College 6).

Extracts 1 and 2 reveal that the female student teachers prefer to use group discussions and individual practice as their self-regulation strategies because of the lecturers’ reactions to their questions. The issue of lecturers’ negative reactions to female student teachers was also raised
by the students who indicated that they do not do anything to enhance their learning of mathematics. This also clarifies why the female student teachers would like to be provided with lecturers that are supportive, motivating and have a positive attitude towards female students. The issue of supporting students to improve their learning and performance in mathematics by attending to their questions during and after lectures, and willingness to help them frequently was also raised by the female students who participated in the study by Eneya et al. (2019). According to Richardson et al. (2012), tendency to seek help from instructors and friends when experiencing academic difficulties correlate positively with university student’s performance. This implies that the female student teachers’ might improve in mathematics performance and participation if they receive proper assistance from their peers as well as their lecturers.

Extracts 3 and 4 are examples of the clarifications made by the female student teachers regarding their need for clear explanations from their lecturers.

Extract 3

The lecturer should not always use group work in dealing with mathematics concepts. Instead of giving us the topic and asking us to discuss on our own in groups, they should firstly explain the mathematics concepts to us clearly and also give clear instructions on what we should be doing in those groups (College 2)

Extract 4

Lecturer should be giving enough information and clarification on mathematic concepts because some of us do not have smart phones to search for information on internet. So instead of teaching us for very short time and asking us to go and search for information, they should spend more time teaching us (College 1)

Extracts 3 and 4 reveal that the female student teachers require their lecturers to spend more time on explaining to them the mathematics concepts and procedures before giving them a group activity. They also require clear instructions from their lecturers regarding the work to be done in the groups. This does not mean that the female student teachers do not like group work, but they require their lecturers to explain the mathematical concepts and procedures clearly for the group activity to be effective. This implies that the quality of the outcomes from group discussions depends on the quality of the explanations and instructions given by the lecturer. These findings confirm Zimmerman (1990) and Özyıdrım et al. (2011) suggestion that for successful use of self-regulation strategies, institutions need to provide different support systems to learners. The suggestion by Zimmerman and Özyıdrım et al. (2011) is also confirmed in extract 5 which are examples of female student teachers’ justifications for their requirement of knowledgeable lecturers.

Extract 5

Give us lecturers who have content knowledge and pedagogical content knowledge in mathematics so that they can help us to understand mathematics by using different teaching methods and representations. This will help us to be able to understand when we practice solving mathematics in our groups or on our own (College 6).
Extract 5 reveals that the female student teachers think that their lecturers do not give clear explanations and do not use different teaching methods and representations during the teaching of mathematics due to lack of knowledge. This confirms Ball et al.’s (2008) argument that there is nothing more foundational to teacher competency than knowledge of their subject matter. Extract 6 and 7 are examples of how the female student teachers explain their requirement of more books and ICT services.

Extract 6

We do not have enough books in the library and our school does not have access to internet for us to search information. We need some extra books in the library both on mathematics content and on how to teach mathematics. We also need internet for searching information (College 3).

Extract 7

It is better that we be assisted with books and internet so that we can be able to search for information required when our lecturers give us group work. If we have more books and internet, we will also be able to search for information that can help us to understand some mathematical concepts that we do not understand in class (College 5).

Extracts 6 and 7 reveal that the female student teachers require more books and internet facility to search for information for their assignments and also enhance their understanding of some mathematical concepts. The issue of supporting students with learning resources like books and internet was also mentioned by university female mathematics students (Eneya et al., 2019). This confirms further that the challenges of lack resources in teacher education institutions limits students’ ability to study effectively and to acquire necessary skills (MoEST, 2020).

Regarding the issue of more time for practicing solving mathematics, the examples of the explanations given by the female student teachers are presented in extract 8.

Extract 8

Our timetable is tight, most of the times we learn different subjects from morning to evening. We need extra time to practice mathematics problems in order to increase our performance. The lecturers should also give us more practice problems for us to practice after classes (College 3).

Extract 8 shows that the female student teachers feel that they would be able to enhance their learning of mathematics if they were given more time to implement their self-regulation strategies of practicing solving mathematics either individually or in groups. For effective group discussions, the female student teachers also require their lecturers to give them more practice problems. This requirement arises due to lack of books and ICT services in the TTCs. Similar results were also reported by Eneya et al. (2019) who found that female mathematics students require more mathematics tutorial questions to help their learning and improve their performance in mathematics.
Conclusion

This study explored self-regulation strategies used by female student teachers to enhance their learning of mathematics and the support they require to boost the effectiveness of their self-regulation strategies. The findings reveal that the female student teachers use different types of self-regulation strategies like practicing solving mathematics in groups or individually, asking their fellow students to assist them, and researching from books and internet. The findings also reveal that there are few students who use the strategy of asking for assistance from their lecturers. This is attributed to the lecturers’ negative attitude towards the students which is reflected by how they react to questions asked by the female student teachers. As such, to enhance the effectiveness of their self-regulation strategies, the female student teachers wish to be supported in many areas including being provided with clear explanations by their lecturers, more time to practice mathematics, more books and internet services, more time to learn mathematics, and more support from their lecturers.

In general, the findings reveal that the TTC female student teachers use several self-regulation strategies to improve their understanding and learning of mathematics. However, for the strategies to be effective, the female student teachers need to be supported in several areas by their institutions. This confirms Sengupta-Irving’s (2012) argument that the promotion of women in mathematics require more than simply recruiting greater numbers of women in the field, “it will require a shift in the teaching of mathematics to a more open and conceptual orientation, greater institutional support for women in higher education, and a social re-education by which gender-based stereotypes and bias are relegated to history” (p.12). These findings are important because they inform all stakeholders that the efforts to close the gender gap in mathematics in Malawi should not only focus on increasing numbers of females in TTCs and other tertiary institutions, but also include support for the female students learning. In this regard the TTCs and other institutions have a big role to play in making the teaching and learning environment gender bias free, conducive to learning for both female and male students, and open for students to ask questions. Without the support of the institutions the objective of increasing female participation in education in general, and in mathematics specifically will not be achieved.

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References


AN EXPLORATION OF THE TEACHING OF CAPACITY IN GRADE 4 IN MALAWI
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University of Malawi

Abstract

This paper discusses findings from a case study which explored the teaching of capacity in Grade 4 in Malawi. Qualitative data was collected from a mathematics lesson using video recording. The study used Mathematics Discourse in Instruction (MDI) as its theoretical framework to explore the teaching of capacity. The MDI framework was chosen because it describes a lesson bit by bit, thereby analysing teaching shifts that take place in a mathematics lesson. This kind of analysis was useful in this study as it enabled a thorough understanding of how teacher’s practices made mathematics available to learners.

The study established that while the lesson goal was to measure capacity of containers in millilitres and litres, the activities and tasks that took place in this lesson may not have prepared the learners fully to enable them to measure capacity. The activities involved the use of known capacities of smaller bottles to fill up bigger bottles. Based on this and other findings, the study suggests that more research needs to be done in Malawi and other countries to guide early grade teachers on how to teach capacity measurement to ensure that learners develop conceptual understanding and underlying skills important for mastery of measuring capacity.

Keywords: Capacity, Mathematics Discourse in Instruction, early grade, Standard and non-standard units.

Introduction

The teaching of measuring capacity in millilitres and litres is a key element of early grade mathematics in Malawi. Learners start by learning measuring capacity in non-standard units in Grade 1 and 2. Terms like bigger than and smaller than are used to compare capacities of different containers that can hold liquids. In Grade 3 and 4, learners are introduced to standard units of capacity. They are taught how to measure capacity in millilitres and litres. (MoEST, 2013). The learning of measurement involves the use and understanding of procedures and the development of conceptual understandings. In literature these are commonly discussed in relation to length measurement (e.g., Battista, 2006; Lehrer, Jaslow, & Curtis, 2003), but they can be transferred to some other measurement concepts like capacity.

Another significant element of the teaching of measuring capacity in early grades is the use of instruments or manipulatives. The manipulatives are meant to physically model situations, demonstrate mathematical concepts and move children’s thinking from the physical to abstract. According to Zacharos, Antonopoulos & Ravinis (2011) the goal of teaching measuring in early years of schooling is for learners to understand the measurement process, to familiarise themselves with the practical uses of units of measurement and to build and use non-conventional measurement tools.
While teachers have clear pedagogical purposes for the tools they select, what is not clear is what learners “see” in the tools they are provided, (McDonough & Cheeseman, 2015). The teaching of capacity to early grade learners should involve learners’ clear understanding of the tools in use and the mathematical ideas behind the use of the tools. If these two ideas are not clear to learners, they may not acquire the intended object of learning. They may be able to follow instructions on how to carry out the activities without understanding the purpose of the activities and the mathematical ideas that the tools are modelling. This becomes difficult for the teacher to ascertain whether learners understand the lesson or not.

In this study, I explored how the teaching of measuring capacity is taught in Grade 4 in Malawi. An in-depth study of one class was done to understand the tasks and examples, teacher’s explanations and learners’ participation. These are the components of MDI, the theoretical and analytical framework for the study.

**Research question**

The study answered the following question:

- **What mathematics was made available to learners during the teaching of measuring capacity in Standard 4?**

**Literature review**

The concept of measurement is practical in nature because it involves learning about everyday activities. For most children measuring length, mass and capacity using non-standard units may not be new. By the time the learners start school they have an idea of measuring using non-standard units. However, the opposite may be true for measuring using standard units. In Malawi, learners are introduced to measuring length, mass and capacity in standard units in Grade 3 and 4.

Several studies have shown that learners have problems to understand and use the concept of unit of measurement. According to Barnett et al (2011) students’ standard unit concepts are rarely developed. Although they may use standard unit labels to name quantity, they often do so without being able to show the meaning of the relevant unit. Measurement units are closely related to rational number units and proportional thinking. Yet many students often mistakenly make additive comparisons rather than making multiplicative comparisons for area units.

Other researchers have pointed out the need for learners’ conceptual understanding and reasoning when they are measuring in standard units. Wilson & Osborne (1992) found out that while the basic idea of direct measurement is simple, there are complex mental accomplishments within measuring which are often downplayed in typical lesson. Kamii (2006) believed that typical instruction focuses more on measurement as an empirical procedure, such as placing paper clips along a pencil and counting them, rather than a procedure requiring reasoning. The same can be said of measuring capacities of containers using a measuring cylinder. The incorporation of opportunities for children to reason, with the purpose of coming to understand foundational or key ideas of measurement, can be enhanced by task design and teacher actions when carrying out those tasks. These and other literature show that while learners bring to class prior knowledge of measuring, there is more that needs to be done
to develop their knowledge and skills. More skills such as precision, comparison and unit iteration are acquired during the learning of measuring length, mass and capacity that may be new to learners. The basic idea of capacity is more than carrying out the measuring procedure, it requires learners’ reasoning and conceptual understanding. Therefore, teachers should be aware of the different skills and knowledge that the teaching of measurement of capacity and other attributes make available to learners.

The terms volume and capacity are used interchangeably in most cases. However, in the Malawian curriculum the two are not taken as the exact same. Capacity is taken as a measure of how much a container can hold. In the early grade’s learners are introduced to measuring capacity in standard and non-standard units. This is done through the use of different containers and hands-on activities. After early grades, learners are introduced to volume.

Statement of the problem

Malawi like other Sub Saharan African countries face a lack and inadequacy of basic teaching and learning resources in schools such as rulers, measuring cylinders and text books. It is common to find more than ten learners sharing one textbook. Such that teachers face challenges to provide explanations that could easily be addressed by the use of resources. For example, it is easier to show learners 100ml of water in a measuring cylinder than to giving an explanation. This also affects learners’ acquisition of mathematical knowledge and skills. Early grade learners require the use of concrete objects to aid their understanding of concepts. Further, the Malawian Primary Mathematics curriculum does not repeat measurement topics within an academic year. Unlike number and basic operations topic that has several repetitions within a year, the three topics under measurement namely; length, capacity and mass, are taught only once in the academic year. As such, it is important for a teacher to make the concepts more accessible to learners. Hence this study sought to find out the mathematics that was made available during the teaching of capacity.

Theoretical framework

This study used Mathematics Discourse in Instruction (MDI) as its theoretical and analytical framework. The framework was developed from extensive research work that was done by the University of Witwatersrand in South Africa. The research was done in poorly resourced and under researched schools in South Africa (Adler, 2017). Shalem & Hoadley (2009) referred such schools to “schools for the poor”. Teachers and learners in “schools for the poor” do not have access to educational “assets” including infrastructure and knowledge resources. Students are typically not academically prepared for the grade they are in (Adler, 2017). It was observed that these conditions were similar to the context in which this study was conducted. There were similarities in terms of lack and inadequacy of teaching and learning resources, and learners’ and teachers’ characteristics. Therefore, these similarities between where the framework was developed and the sample school influenced my choice of MDI framework. Secondly, the MDI framework describes the lesson bit by bit, thereby analysing teaching shifts that take place in a mathematics lesson. I found this way of analysing the lesson useful in this study as it enabled the thorough understanding of teacher’s practises and how each practice made mathematics available to learners.
In describing the framework, Adler & Ronda (2015) represents it diagrammatically as below:

![Diagram of MDI framework]

Figure 1: Constitutive elements of MDI

The four constitutive elements of MDI are object of learning, exemplification, explanatory talk and learner participation. Object of learning is regarded as the lesson goal (*that which students are to know and be able to do*). The lesson goal needs to be clear as it is what the teacher intends to achieve in the lesson. In the diagrammatic representation above, Adler & Ronda (2015) separates the object of learning from the other components of MDI. The three components of exemplification, explanatory talk and learner participation are viewed as the key meditational means or cultural tools in a typical mathematics classroom instruction. These tools are used to achieve the object of learning. Exemplification which is divided into *examples* and *tasks* is a common practice in mathematics teaching where lessons start with examples followed by similar tasks for learners’ practise. Explanatory talk involves communication by the teacher that takes place during the lesson. It is divided into *naming* (*words used to name the mathematics being discussed*) and *legitimation* (*explanations of what is to be known and done in the lesson*). Learner participation on the other hand allows learners to participate in the teacher’s communication even if it may be in form of mostly listening to the teacher (Adler, 2017). It also involves their participation in answering questions.

The key components of MDI framework described above were summarised in the analytic framework to show how each component is used to analyse a lesson or a set of lessons. Table below shows the analytic framework for MDI (adopted from Adler & Ronda, 2015).

Table 1: MDI analytic framework

<table>
<thead>
<tr>
<th>Object of learning</th>
<th>Exemplification</th>
<th>Explanation</th>
<th>Legitimating criteria</th>
<th>Learner participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples</td>
<td>Tasks</td>
<td>Talk/Naming</td>
<td>Level 1NM (Non-Math)</td>
<td>Level 1 - Learners</td>
</tr>
<tr>
<td>Examples provide opportunities within lesson for learners to experience Level 1 - similarity or contrast</td>
<td>Level 1 – Carry out known operations and procedures e.g. multiply, factorise, solve Level 2 - Apply level 1 skills; &amp; learners have to decide on (explain choice of) operation and/or procedure to use e.g.</td>
<td>Level 1- Colloquial language including ambiguous referents such as this, that thing, to refer to objects Level 2 - Some math language to</td>
<td>Visual: Visual cues or mnemonics Metaphor: Relates to features or characteristics of real objects Level 2 M (Math) (Local)</td>
<td>answer yes/no questions or offer single words to teachers unfinished sentence</td>
</tr>
</tbody>
</table>
The MDI analytic framework above shows different levels of the components of the three key meditational means in a typical mathematics lesson. Exemplification, explanatory talk and learner participation have been divided into 3 or 4 levels each to describe what happens in a mathematics lesson. This analytic framework has been used in this study to describe the sample lesson.

**Study methodology**

Case study research method was used to collect qualitative data from a Grade 4 class. Bassey (1999) argues that case studies present research data in a more publicly accessible form than any other kinds of research report. He further contends that educational case studies are concerned with enriching the thinking and discourse of educators through the systematic and reflective documentation of evidence. In this study, the lesson was divided into four events to enable systematic and focused documentation and analysis of the case. This is also in line with the MDI framework that the study used to analyse the data.

Yin (2009a) defines a case study as:

“An empirical inquiry about a contemporary phenomenon (e.g., a “case”), set within its real-world context—especially when the boundaries between phenomenon and context are not clearly evident” (Yin, 2009a, p. 18).

In this study, a case under investigation was a lesson on capacity and the classroom was regarded as the natural environment. Data collection in this class did not change any features of the class including learners, the teacher, teaching and learning resources and their classroom. All factors remained unchanged during the time of data collection.

1. **Sample and sample size**

The class was purposively sampled to ensure that the teacher was teaching capacity during the time of data collection. The sampled class had 58 learners out of which 32 were girls and 26
were boys. Their ages ranged from 8 -14 years old. The only age restriction in Malawi is that children should start Grade 1 at 6 years old. There is no age restriction in the other grades. Therefore, it is common to find learners with different ages in the same grade. The classroom had one chalkboard, one chair and one table for the teacher. All the learners were sitting on the flour. The class had posters for different subjects offered in Grade 4.

In terms of teaching and learning materials for the lesson under observation, there were 24 bottles of different capacities ranging from 500ml to 2l, five 20l buckets and five 250ml cups. The teacher had a Teachers’ Guide and learners were sharing 12 textbooks present in class.

ii. **Data collection and analysis**

Data was collected using the following methods:

a. Direct observation- The researcher was present during the lesson and observed and took notes of what was going on in the classroom. Both the human actions and physical learning environment were carefully noted.

b. Document review- The researcher reviewed content on capacity from the Teacher’s Guide, Learner’s book and the syllabus. These are the basic documents that mathematics teachers use in Malawi. The teacher’s lesson plan was also analysed.

c. Video recording- To ensure that more data was captured and kept for further review, the whole lesson was video recorded.

The audio-visual data were transcribed and the lesson was divided into four events. Each event represented an activity that took place during the lesson. The notes collected during direct observation and document review formed part of the findings of the study. They also helped to triangulate the data in terms of comparing the implemented curriculum and the planned curriculum.

**Findings of the study**

This section presents the sample lesson and its analysis based on the MDI analytic framework.

**A lesson**

The title of this illustrated lesson was “Kukula kwa zinthu” meaning Capacities of containers. The following were the success criteria of the lesson which in MDI are object of learning:

- Measure capacities of containers in litres
- Measure capacities of containers in millilitres

The lesson was divided into four events, with a new event distinguished by a new activity. The activities ranged from teacher asking questions and learners answering questions, hands-on measuring activities and teacher explanations. Below is a detailed description of the lesson:

<table>
<thead>
<tr>
<th>Event 1: Identifying capacities of bottles</th>
</tr>
</thead>
<tbody>
<tr>
<td>The teacher showed learners bottles of 1l, 2l, 3l and 5l one at a time and asked them to identify the capacity of each bottle. The bottles were empty juice or cooking oil bottles that are commonly found in Malawi and therefore familiar to learners. The common question was:</td>
</tr>
</tbody>
</table>
[Teacher: What is the capacity of this bottle?]
[Learners: 2l]

**Event 2: Discussing the relationship between any two bottles**
The teacher held a 2l and 1l bottle in her hands. She then asked learners to identify the capacity of each bottle which they did. She then asked the learners: How many 1l bottles can fill up a 2l bottle? The teacher repeated this activity by showing learners a 500ml and a 1l bottle. She asked learners that how many 500ml bottles can fill up a 1l bottle? The teacher then wrote on the chalkboard: 1l = 1000ml

[Teacher: How many 500ml can fill up a 1l bottle]
[Learners: 2 bottles]

**Event 3: Establishing the relationship between two bottles**
In this activity learners were put in four groups. Each group had between 12 and 15 learners. The teacher distributed a 500ml, 1l and 2l bottles to each group of learners. She also gave each group a 20l bucket of water. The teacher asked learners to find out how many 500ml bottles can fill up a 2l bottle. The learners repeated the same activity using a 1l bottle. Learners were drawing water from the 20l bucket and filling up one bottle and pour in another bottle

[Teacher: How many 1l bottles can fill up a 2l bottle?]
[Learners: 2]

**Event 4: Explaining the relationship between millilitres and litres**
In this event, the teacher asked learners to explain what they were doing in their groups. One member of each group explained the process of establishing the relationship between any two bottles like this:

[Teacher: Explain to the class what you did in your group and what you found]
[Learners: We were given a 2l and 500ml bottle. We were also given a bucket of water. We drew water from the bucket using a 500ml bottle and poured the water in a 2l bottle. We found that the 500ml bottle fills up a 2l bottle four times. Therefore 2000ml = 2l]

The teacher wrote on the chalkboard the following:

i. 500ml + 500ml = 1000ml = 1l
ii. 500ml + 500ml + 500ml + 500ml = 2000ml = 2l

The teacher then asked if any learners had their own bottles. There were 100ml, 150ml, 250ml and 500ml bottles of water or juice for learners. The teacher was asking questions like: how many 100ml bottles can fill up a 200ml bottle? How many 250ml bottles can fill up a 500ml bottle? The lesson was extended to other capacities not present in class during the lesson. The teacher asked questions like: How many 2l bottles can fill up a 10l bottle? How many 5l bottles can fill up a 10l bottle?

**Analysis of findings**
The MDI framework was used to analyse the above lesson and events. In this section, I present the analysis of the lesson based on the four components of MDI.

1. **Object of learning**
The object of learning is regarded as the lesson goal (that which students are to know and be able to do). In this lesson, the teacher came up with two lesson goals and these were: measure capacity of a container in litres and measure capacity of a container in millilitres. The four captured events had ml or l as the core content of the lesson. It was clear that the teacher and learners’ talk and hands-on activities were emphasising on the standard units of measuring capacity.
2. Exemplification
Exemplification consists of examples and tasks. The mathematical goal is achieved through elaborated examples and given tasks. The lesson under discussion did not have specific examples because of its nature. It involved a lot of question and answer, explanations by both the teacher and learners and hands-on activities.

In terms of tasks, I analysed the last event of the lesson. In this event learners were asked to explain what they did in their respective groups, establishing the relationship between millilitres and litres and this knowledge was extended to other capacities of containers not present in class. In other words, the tasks were from capacities of bottles present in class to those not available in class. Therefore, I observed level 1 and level 2 type of tasks being achieved by the learners, according to the MDI framework. The level 1 tasks included carrying out known procedures of measuring capacities of bottles like 1l and 2l. While level 2 tasks included applying level 1 skills to determine how many 2l bottles can fill up a 10l bottle, for example. The learners were also able to provide explanations for the procedures they were carrying. This is also regarded as level 2 task.

3. Explanation
For the lesson to be achieved it has to be clear and justified and legitimated through explanatory talk and learner participation. Explanatory talk is simply explanations that teachers provide in the lesson. The MDI framework divides teacher explanatory talk into naming and legitimations. In this case naming are both mathematical and non-mathematical terms used in the lesson while legitimations are explanations of mathematical ideas and procedures. The two are divided into three levels (low to high) depending on the teachers’ use of mathematical language in the lesson. In terms of naming, it was observed that the teacher was operating at level 1, 2 and 3 according to the MDI framework. Examples of the teacher’s level 1 naming included the use of phrases such as “this thing” to refer to ml or l, “this one” to refer to a bottle. Examples of level 2 naming by the teacher include the many instances she was naming the standard units of measuring capacity, millilitre and litre. This was observed throughout the 4 events of the lesson. The teacher was also using appropriate names and procedures for carrying out activities (level 3). For example, in event 4 where she explained the relationship between millilitres and litres as: \[500\text{ml} + 500\text{ml} = 1000\text{ml} = 1\text{l}\].

In terms of legitimations, it was observed that the teacher was operating on levels 1 to 2 according to the framework. Her explanations moved from the use of concrete objects (bottles) to some real life application. In the first three events the teacher was explaining about capacity with the aid of 500ml, 1l and 2l bottles. Learners were able to see that the bottles had different capacities. Later, she asked learners to fill up a 2l bottle using a 500ml or 1l bottle to allow them understand the relationship between the measured capacities. And in event 4, the teacher asked learners to apply their knowledge of 2l by filling up a 10l bottle using a 2l or a 5l bottle.

4. Learner participation
The MDI framework, describes learner participation in terms of levels of answers provided by learners. It was observed that learners operated at level 1 and 2 in this lesson. Their answers in events 1 and 2 were usually single words answers. For example, the teacher asked about the capacities of different bottles and their answers were 500ml, 1l, 2l, and 5l. In events 3 and 4...
learners answers involved phrases and sentences especially when they were explaining the procedure of filling up one bottle using a smaller bottle. For example, learners were able to explain that a 10 l bottle can be filled up by a 2 l bottle 5 times. This and other instances showed learners’ ability to operate at level 2.

**Discussion of findings**

This study aimed at exploring the teaching of measuring capacity in an early grade class in Malawi. The study sought to answer the following question: What mathematics was made available to learners during the teaching of measuring capacity in Standard 4?

The teacher intended to teach learners how to measure capacities of containers in millilitres and litres. Measure according to the dictionary means “ascertain the size, amount, or degree of (something) by using an instrument marked in standard units” (Oxford Dictionary). It was observed that in this lesson, the teaching of measuring capacity was based on using bottles of known capacities to fill up other bottles. There was no special instrument to verify that the capacities of bottles they were using were indeed 500 ml, 1 l or 2 l. Such that, the measuring of capacity skill was dependent on already known measures. This limited learners’ attainment of measuring skill which includes precision and reading from the measuring instrument.

According to the Teachers’ Guide, the three skills that learners ought to attain in this topic were measuring capacity, estimating capacities of containers and converting capacity from litres to millilitres and vice versa. It was observed that the only skill that learners were taught was measuring capacities in millilitres and litres. Although the teacher also introduced changing from millilitres to litres, the skill was not emphasised in this lesson.

It was observed that most of what the teacher did in this lesson were suggested activities from the Teachers’ Guide. In their study of the use of mathematical tasks of teaching and the corresponding LMT measures in the Malawi context, Kazima, Jakobsen & Kasoka (2016) found out that “teachers follow the Teacher’s Guide and the textbook diligently without questioning their applicability. Malawi teachers tend to take Teacher’s Guide and textbook as prescriptions of what and how to teach and not as suggestions,” (p. 179).

In terms of exemplification, the study analysed what learners were doing in class as their tasks. Their main task was events 2 to 4 where they were using smaller capacity bottles to fill up bigger bottles and so establishing the relationship between different capacities. It was noted that the learners were using familiar and locally found bottles which was easier for them to recognise the capacities of the bottles. It was observed that their tasks did not include aspects of estimation and converting from litres to millilitres. These two skills have been highlighted as important skills in the curriculum (Teachers’ Guide, MoEST, 2013). The skill of estimation would help learners to find the capacity of unknown bottles or containers. This is an important everyday life skill. The lesson could involve the use of bottles or other smaller containers like cups, jugs and basins to allow the learners to estimate their capacities and later measure and compare with their estimates. This was seen as a missing opportunity for learners to understand capacities of different containers and bottles other than the familiar and commonly used and already marked 500 ml, 1 l and 2 l ones.
Teacher explanation which involves naming and legitimation was also analysed. It was observed that the explanations from the teacher were from level 1 to level 3. There was evidence of the use of standard units of measuring capacity and mathematical procedures. Adler (2017) reported that what teachers say and how they say it matters in mathematics lessons. This is more critical in early grades where learners depend mostly on teachers to learn. It was observed that in this class learners were able to use and name standard units of capacity properly and that the teacher emphasised on appropriate naming of the same.

Since the four components of MDI are connected and interrelated, what happens in the other components affect the other components. While, it was noted that learners were able to carry out given tasks, the study found out that learners were always following instructions from the teacher. Learners were not given an opportunity to discuss or suggest on how they could carry out activities on measuring capacity of containers. In a study of measuring length in standard units, Mwale (2020) observed that learners were in most cases following instructions without giving their ideas on how to carry out the activities. This observation was also made in this study. Consequently, raising the question of whether learners attained the conceptual understanding of measuring capacity in millilitres and litres and understood the mathematical ideas underlying the tasks they were carrying out in the lesson.

**Conclusion**

The MDI analytical framework was used to analyse a Grade 4 lesson on measuring capacity in this study. The lesson, was regarded as a case in this case study and qualitative data was collected and analysed to ascertain the mathematics that was made available for learners to learn. Using the MDI framework, the lesson was divided into four events, in which each event was characterised by a change of activity. I analysed the three cultural tools of a typical mathematics lesson according to MDI; exemplification, explanatory talk and learner participation based on their level of complexity. The object of learning was also analysed to find out if the intend goal of the lesson was achieved and consequently to ascertain the mathematics that was made available for grade 4 learners to learn.

The study established that while the lesson goal was to measure capacity of containers in millilitres and litres, the activities and tasks that took place in this lesson may not have prepared the learners fully to measure capacity. The activities involved the use of known capacities of bottles and using the same to fill up bigger bottles. The question that this study raises is; Can the learners measure capacities of unknown bottles? Secondly, the study also found out that some important skills in measuring capacities were not emphasised in this lesson. These are estimation and converting from litres to millilitres and vice versa. These are important skills that learners need to acquire in order to work with capacities other than the ones they learned in class. Thirdly, findings of this study showed that learners were not given an opportunity to suggest or come up with ways of measuring capacity even though they were using known or familiar bottles. The teacher was explaining the procedures and learners were simply following the same. Fourthly, it was observed that the teacher followed the suggested teaching activities provided in the Teachers’ Guide. Therefore, what the teacher did in this class can be regarded as the common way of teaching measuring capacity in Grade 4 in Malawi.
Based on these findings, I highlight the following as the implications of teaching measuring capacity in Grade 4 in Malawi: many learners may not be able to measure capacity of containers using new and unfamiliar instruments by the time they finish Grade 4 because they were not adequately prepared with knowledge and skills to do so. Secondly, teaching is compromised by the lack of or inadequacy of resources such as measuring cylinders that would enable the teacher and learners to use during the teaching of measuring capacity. Thirdly, measurement involves many embedded skills such as the appropriate use of measuring instruments, accuracy and ability to read from the measuring instrument. As such, if learners are not introduced to these measuring instruments, they are denied an opportunity to acquire more skills than just measuring. Therefore, there is a need to emphasise on the mathematical aspects and skills that learners acquire through the learning of measuring capacity and measurement in general.

In conclusion, more research needs to be done in Malawi and other countries to guide early grade teachers on how to teach capacity measurement when there is lack of resources to work with. Teachers should be made aware of the underlying skills and knowledge that learners need to acquire when teaching capacity. This will help them to emphasise on the specialised mathematical ideas when teaching. The teaching of measuring capacity like other mathematics ideas should aim at building learners’ conceptual understanding among others. Otherwise, procedures on how to carry out activities only, limit how much learners acquire in the lesson.

References


JUMPSTART PROGRAMME IMPACT ON MATHEMATICS LEARNING OUTCOMES: A CROSS-SECTIONAL QUASI EXPERIMENT USING THE EARLY GRADE MATHEMATICS ASSESSMENT

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University of Johannesburg

Abstract

This paper contributes to the research agenda on intervention studies and their impact on learning outcomes. It focuses on early grade mathematics in South Africa by drawing on four years of cross-sectional data (n = 5,724) from treatment and control primary schools in the same district in Gauteng. Early Grade Mathematics Assessments (EGMA) were administered to a random selection of learners in both school groups over a period of 4 years. Findings show a statistically significant difference in mean attainment on the EGMA assessment in the JumpStart schools (effect size of 0.52) and with further improvements evident after 3 years (effect size of 0.94). These effect sizes are compared to existing South African studies as well as meta-analysis of studies from low- and middle-income countries. Benchmarks for EGMA raw score attainment at Grade level in the Ekurhuleni South district of Gauteng (n = 2,625) are provided.

Introduction

Mathematics attainment in South Africa (SA) remains an area for concern. Various studies have shown that SA children’s performance in mathematics is much lower than in other African countries of a lower socio-economic status (SES) and that only about seven percent of SA Grade 6 learners from lower SES groups achieved “Advanced” levels of mathematics (SACMEQ, 2017).

There have been various interventions to improve attainment, with increasing recognition that the problems stem from early on in the schooling system. Some of the initiatives taken by the national Department of Basic Education (DBE) to address these challenges include providing bursaries for aspiring graduates to study at university following teaching of primary school mathematics as a career of choice; the provision of materials and workbooks that are intended to consolidate the teaching of languages and mathematics, particularly at the Foundation Phase (FP), and the development of a ‘Teaching Mathematics with Understanding’ framework.

In a recent book guiding policy makers and administrators in Africa, Goldman and Pabari (2020) offer compelling reading about using evidence to inform decision making – in both health and education contexts. They note that global evaluation research has shifted from single evaluations to evaluation synthesis studies. This claim, however, pre-supposes that there are single evaluation studies, the results of which are published and across which synthesis is possible. In the resource-constrained context of Africa, and the Southern African region in particular, there remain a paucity of experimental designs which document impact on learning outcomes, from which an evaluation synthesis can be drawn.
Hazell (2019) conducted a meta-evaluation study of promising interventions in SA schools which have been implemented on a variety of scales over the past five years. She found two types of interventions that have been evaluated rigorously and have demonstrated promising results. She refers first to Fleisch’s (2018) “education triple cocktail” of learning, teaching and support materials (LTSM), lesson plans, and individual coaching and then to interventions which commence with diagnostic testing and target LTSM and teaching to learners’ current ability level.

In this paper, evaluation research of the impact of the JumpStart programme in 20 schools in a single district in Gauteng province is presented. A standardised and validated instrument – the Early Grade Mathematics Assessment (EGMA) was used in a cross-sectional quasi-experimental design which was repeated over a period of four years. This paper has a three-fold purpose. Firstly, the paper explores and offers a benchmark for an education district that tracks learner performance in early mathematics. Secondly, it makes a contribution to existing impact research findings on South Africa interventions to improve mathematics at the Foundation Phase. Thirdly, the paper contributes to the research-base on interventions in SA primary schools which have a quasi-experimental design to analyse impact on mathematics learning outcomes.

**Intervention studies in developing country contexts**

In order to make sense of the results of the quasi-experiment involving the JumpStart schools, it is necessary to first reflect on the assessment instruments used to measure early grade attainment in mathematics as well as what kinds of shifts in attainment can be considered impactful. We discuss each in turn.

**Assessing early grade mathematics**

For impact assessment to be meaningful, standardised and validated assessment instruments are required. These are in short supply in our Southern African context. As a result, some evaluation studies have relied on national standardised assessments. The Annual National Assessments (ANAs) were administered annually by the DBE, up to 2014. These were national assessments, but were not validated, making year-on-year comparison between assessments difficult.

As the JumpStart intervention spanned Foundation Phase (Grades R – 3), a standardised and validated instrument which could consider progression over this phase was required. The Core Early Grade Mathematics Assessment (EGMA) was selected for this task. The EGMA is an orally-administered assessment of the core mathematical competencies taught in early primary grades. EGMA development was undertaken by RTI International and funded by the United States Agency for International Development (USAID). The Core EGMA offers an opportunity to determine whether children are developing the fundamental skills upon which other mathematical skills build, and, if not, where efforts might be best directed as described in Platas, Ketterlin-Gellar, Brombacher and Sitabkhan (2014).

The Core EGMA is described as “an assessment of early mathematics learning, with an emphasis on number and operations” (Platas et al., 2014). The EGMA test is a battery of seven
testlets each focusing on assessing one set of mathematical skills: addition, subtraction, addition and subtraction together, number identification, number comparisons, number patterns (missing number) and word problems. Given the specific focus on number, we refer to the underlying construct of the EGMA as “number sense”.

In total there are 86 items that constitute the test. The test has been developed and used in different contexts with results that attest to its validity. The test had a reliability index of 0.95 and a separation index of 4.18, which are considered to be well above the recommended minimum values of 0.80 and 2, respectively (Linacre, 2020). The separation index is an indicator of the number of “ability groups” that the instrument detects from the testee responses. Any test that cannot detect at least two groups, competent and incompetent, among the testees may not be useful for informing intervention decisions. The EGMA test has the ability to detect up to four ability groups among test respondents, making it good for a diagnostic instrument.

The Core EGMA has been designed for both summative and formative assessments. It can be used to determine how students in a country are performing overall compared to its stated curriculum. It can also be used to examine the effectiveness of specific curricula, interventions, or teacher training programs, as was the case in this study. Platas, et al. (2014) offer detailed explanation of the core EGMA’s development, descriptions of its technical adequacy as well as the details of its validity. Processes for local adaptation and training of assessors are also prescribed. The core EGMA is meant to be locally adapted to fit the needs of the local context, particularly with regard to language where it is administered in the language of learning and teaching for mathematics at FP in the school. **Measuring impact of interventions**

Across a number of recent meta-review and synthesis studies, interventions that target teachers and aim to enhance the quality of instruction, via the introduction of specific teaching methods and/or capacity building, alongside the provision of LTSM, are identified. Their effect sizes are summarised in Table 1.
<table>
<thead>
<tr>
<th>Type of intervention</th>
<th>Focus</th>
<th>Average effect size</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve teaching quality: pedagogical interventions</td>
<td>General</td>
<td>0.92</td>
<td>Conn (2017)</td>
</tr>
<tr>
<td>Improve teaching quality: instructional time interventions</td>
<td>General</td>
<td>0.46</td>
<td>Conn (2017)</td>
</tr>
<tr>
<td>Use computers or technology</td>
<td>General</td>
<td>0.15</td>
<td>McEwan (2015)</td>
</tr>
<tr>
<td>Teacher training</td>
<td>General</td>
<td>0.14</td>
<td>McEwan (2015)</td>
</tr>
<tr>
<td>Teacher-level structured pedagogy interventions.</td>
<td>Mathematics</td>
<td>0.14</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>Class size and/or composition</td>
<td>General</td>
<td>0.12</td>
<td>McEwan (2015)</td>
</tr>
<tr>
<td>Merit-based scholarships</td>
<td>Mathematics</td>
<td>0.11</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>Contract or volunteer teachers</td>
<td>General</td>
<td>0.10</td>
<td>McEwan (2015)</td>
</tr>
<tr>
<td>School feeding</td>
<td>Mathematics</td>
<td>0.10</td>
<td>Snilstveit et al. (2015).</td>
</tr>
<tr>
<td>Student and/or teacher performance incentives</td>
<td>General</td>
<td>0.09</td>
<td>McEwan (2015)</td>
</tr>
<tr>
<td>Extra time in school</td>
<td>Mathematics</td>
<td>0.09</td>
<td>Snilstveit et al. (2015).</td>
</tr>
<tr>
<td>LTSM</td>
<td>General</td>
<td>0.08</td>
<td>McEwan (2015)</td>
</tr>
</tbody>
</table>

Besharati and Tsotsotso (2015) investigated the influence of target phase and found that interventions implemented in lower grades and phases of the SA schooling system have a greater effect on learner performance. It is therefore important to compare like with like, and use available evidence in the FP, to reflect on intervention studies in the early grades. Hazell, Spencer-Smith and Roberts (2019) assert that the effect size of interventions identified as promising in international synthesis studies is often quite small, upwards of around 0.1 of the standard deviation (SD). Interventions identified as promising in the SA context have slightly larger effect sizes (upwards of around 0.2 SD) and the effect is often measured after a period of two years. In some instances, effects found after a period of one year were found to have tapered off a year later. The following offers a tabulation of researched effects, in the large-scale interventions in SA FP settings:
Table 2: Average effect sizes of meta evaluations in SA

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Subject</th>
<th>Average effect size (SD)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauteng Primary Literacy and Mathematics Strategy (GPLMS) after 1 academic year</td>
<td>Mathematics Grades 1 – 3</td>
<td>0.35–0.61</td>
<td>Fleisch, Schöer, Roberts, and Thornton, (2016)</td>
</tr>
<tr>
<td>GPLMS after 2 academic years</td>
<td>Mathematics Grades 1 – 3</td>
<td>0.5</td>
<td>Fleisch et al. (2016)</td>
</tr>
<tr>
<td>Early grade reading study (EGRS): Learners whose teachers received LTSM, training, and coaching</td>
<td>Language and literacy Grades 1 – 3</td>
<td>0.25</td>
<td>Kotzé, Fleisch, &amp; Taylor (2018)</td>
</tr>
<tr>
<td>R-Maths intervention in WCED</td>
<td>Mathematics Grade R – 1</td>
<td>0.2</td>
<td>Hazell, Spencer-Smith &amp; Roberts (2019)</td>
</tr>
<tr>
<td>Early Grade reading study: LTSM and training only</td>
<td>Language and literacy Grades 1 – 3</td>
<td>0.12</td>
<td>Kotzé, Fleisch, &amp; Taylor (2018)</td>
</tr>
<tr>
<td>GPLMS after 4 academic years</td>
<td>Mathematics Grades 1–4</td>
<td>No effect</td>
<td>Fleisch et al. (2016)</td>
</tr>
</tbody>
</table>

It is worth emphasising that the effect sizes in early grade mathematics in SA in this tabulation are large scale (province or district wide). All adopt elements of what Fleisch (2018) refers to as an educational triple cocktail: (1) quality structured learning materials, (2) teacher training and (3) school-based mentoring or coaching. There are two slight variations: The R-Maths intervention in the WCED did not have direct school-based mentoring but this was offered via subject advisors; and the Early Grade Reading Study omitted school-based mentoring or coaching.

Project setting

JumpStart has managed an intervention to improve the teaching and learning of mathematics with a focus on the FP in the District of Ekurhuleni South in Gauteng since 2016. The Ekurhuleni South district is described by the DBE as being “urban with some informal settlements” (DBE, 2015). The predominant home languages are: English (30%), isiZulu (26%), Sesotho (14%) and Afrikaans (14%). Relative to other districts in SA, Ekurhuleni South is small in geographic area, caters for a large number of learners and has a very high population density. This is a relatively well performing district, within one of the top performing provinces in SA. Most the schools in this district are classified as quintile 3\(^3\), with 52% of the schools being no-fee schools (DBE, 2015).

Project design

JumpStart has developed an intervention which is quite distinct from the Fleish (2018) triple cocktail. The triple cocktail comprises of (1) quality structured learning materials, (2) teacher training and (3) school-based mentoring or coaching. For JumpStart, while there are structured

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\(^3\) South African public schools are classified into quintiles with quintile 1 reflecting schools in the most under-resources communities, and quintile 5 schools being in the most affluent communities. Pro-poor policies legislate that parents do not pay schools for children in quintiles 1-3 (no fee schools), and these schools receive the greatest subsidy per child.
learning materials, there is limited to no teacher training and no school-based mentoring of teachers. The JumpStart intervention is described in detail in Roberts (2021). The primary inputs in this JumpStart intervention are the Number Sense workbooks, use of which is supported by twice-weekly support by school interns (Roberts, 2021). These interns are previously unemployed young SA adults who are employed for a year or two to perform mathematics tutoring in the classroom. Through the internship they gain valuable employment experience, develop a new skill set and, in some cases, find a path to higher education. In addition, the monthly allowance for these interns is subsidized by public youth employment funds. In this way two problems are addressed simultaneously: youth unemployment and lack of work experience, and additional capacity in schools to assist teachers. To facilitate the smooth running of these classroom sessions, JumpStart’s project delivery manager and two team leaders engage in both formalised workshops and informal mentorship to support interns in the classroom. The interns in the schools are further supported with school-based visits by a JumpStart project director.

As explained in Roberts (2021) learners experience the JumpStart intervention as having two mathematics lessons per week where their normal class teacher is supported by an intern and they work through a Number Sense workbook. The workbook is graded to the level of development of the learners. The Jumpstart intern moves around the class with a tablet application and marks the learners’ work.

When reflecting on the approach to mathematics, the JumpStart intervention is detailed and coherent as it builds on the research base and instructional design of the Number Sense Mathematics Programme. This has been created to support children’s development of a “robust sense of number and a deep understanding of mathematics” (Brombacher & Associates, 2019). The materials consist of 12 work books (four for each grade level). Each workbook has 48 pages and focuses on the development of key mathematical concepts. The workbooks are designed to complement the curriculum focusing on key skill development: work fluently and flexibly with numbers and number concepts; a rich understanding of the meaning of number; a wide range of effective strategies for solving a large variety of number problems.

**Research design**

Since its inception in 2016 the JumpStart Project has grown in three Phases with changes in scope and scale as follows: Phase 1 commenced in 2016 with 5 schools, Phase 2 in 2017 with another 5 schools and Phase 3 in 2018 with another 10 schools. In total there were 20 schools sampled for intervention (treatment) from Ekurhuleni Education District and ten schools, from the same district, included for control purposes.

To analyze learner outcomes, a quasi-experimental study design was adopted. Performance of a random selection for learners across Grades 1 to 3 in treatment and control schools (all in Ekurhuleni South district) assessed annually was analysed. As such, performance snapshots were taken for different populations at particular points in time. For the:

(1) Control schools there was a snapshot at baseline and then again after one academic year;
(2) Phase 1 treatment group snapshots were available at baseline and then three further points in time (over a 3-year period),

(3) Phase 2 treatment group snapshots at baseline and then two further points in time (over a 2-year period);

(4) Phase 3 treatment group snapshots at baseline and then one snapshot a year later was available.

**Research questions**

The focus of this paper is on mathematics learning outcome measured using the Early Grade Mathematics Assessment (EGMA). We consider whether the JumpStart intervention made any impact on learner attainment in this assessment at Grade 1, 2 and 3. We first consider whether the EGMA attainment by grade differed between the treatment and control groups, at baseline and after one year. We then explore whether there were changes evident over time (after 1, 2 and 3 years of JumpStart intervention) in the cross-sectional performance by grade in treatment schools.

**Sample and sampling of schools**

A two-stage sampling design was applied. In the first stage the Ekurhuleni Education District drew the sample of schools in which they considered intervention would benefit both the school and the learners. In the second stage samples of FP learners were randomly selected (sequenced by height and selecting every fifth learner) to take the EGMA test under the guidance of a trained JumpStart intern.

**EGMA test administration**

At both control and treatment schools, the EGMA assessment was administered orally with a JumpStart intern reading out the instructions to the learners. The sampled learners were grouped and accommodated in one classroom and each was given a tablet on which they complete the assessment. Their work on the assessment was preceded by some sample questions, where the trained intern ensures that every child can use the tablet. The learners then make their choice of answer in the tablet. The intern then moves on to the next question, reads this out and all learners’ answer. This is the same way that Annual National Assessments were administered by teachers with their classes (DBE, 2012).

The EGMA script or guide was provided in English and the intern translated it, on the spot into the language of teaching and learning of the school. This could be a design and data collection weakness as it means that the tests were not standardized and tightly scripted for each language. However, as the EGMA was administered by the same test administrators, and in the same way across the control and treatment schools, the comparison in attainment across the schools is considered adequate.

**Analysis**

**Data preparation**

Preparation of data for analysis included merging all the separate files for each year cohort of learners and compiling one Master database in Microsoft Excel. Variables such as the quintile
level and the school size were sourced from the DBE Education Management Information System database and included into the master dataset because they were considered important factors in intervening for improvement.

As a starting point, the treatment schools were compared to the control schools. We found that the control schools had a higher proportion of Quintile 4 and 5 schools. Spaull and Kotze (2015) showed that the average Grade 3 student in a Quintile 5 school is functioning approximately three Grade-levels higher than their counterpart in Quintiles 1–3. Consequently, we excluded the two control Quintile 5 schools as they skewed the control group mean attainment.

**Table 3: Sample schools in the Project (excluding quintile 5 control schools)**

<table>
<thead>
<tr>
<th>School Quintile</th>
<th>Control schools</th>
<th>Treatment schools</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quintile 1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Quintile 2</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Quintile 3</td>
<td>3</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Quintile 4</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Quintile 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
<td><strong>19</strong></td>
<td><strong>27</strong></td>
</tr>
</tbody>
</table>

In the treatment schools the EGMA tests were administered at the outset of engagement with JumpStart (baseline) and then each academic year thereafter. This gave a dataset where random samples of learners from the various cohorts were assessed at baseline, after 1, 2 and 3 years of JumpStart intervention. In the control schools’ random samples of learners were assessed at baseline, and then one academic year thereafter. EGMA data was obtained from 5,724 learners during the four years of the programme as presented in Table 4.

**Table 4: Numbers of assessed learners in the Jumpstart Programme**

<table>
<thead>
<tr>
<th></th>
<th>Treatment schools</th>
<th>Control schools</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Year 1</td>
<td>Year 2</td>
</tr>
<tr>
<td>Grade 1</td>
<td>500</td>
<td>438</td>
<td>316</td>
</tr>
<tr>
<td>Grade 2</td>
<td>479</td>
<td>520</td>
<td>428</td>
</tr>
<tr>
<td>Grade 3</td>
<td>441</td>
<td>516</td>
<td>436</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1420</strong></td>
<td><strong>1474</strong></td>
<td><strong>1180</strong></td>
</tr>
</tbody>
</table>

We focused on EGMA attainment in Grade 1 to 3 where assessments took place prior to the transition to teaching mathematics in English (in grade 4) and where all group sizes exceeded 145 learners.
Analysing changes in EGMA raw scores or EGMA levels

By design, the EGMA results are reported to teachers in four EGMA levels that are hierarchical in terms of the mathematical complexity that learners need to demonstrate. The fact that the same EGMA instrument is used across grades makes it possible to trace development in mathematical skills (number sense) as learners’ transit from grade to grade. For diagnostic purposes, so that teachers can respond to the findings, the results are reported as the proportions of children in a grade or class that attain each EGMA level.

In this paper we make use of EGMA raw scores as we can calculate mean and standard deviations for each grade level, to focus on JumpStart impact over time.

Adjustments for time of year when EGMA assessments were administered

JumpStart interns administered EGMA tests annually between February and July, with the majority of tests being administered in March. We made use of the baseline data from the treatment schools and control schools, to calculate benchmarks for EGMA mean scores and EGMA levels. A total of 2,625 tests were administered across Grade 1-3 in 28 schools in the Ekurhuleni district in control schools or at baseline (prior to intervention) in treatment schools.

Table 5: Control and baseline scores in the Jumpstart programme

<table>
<thead>
<tr>
<th>EGMA benchmarks (Raw scores)</th>
<th>Control baseline</th>
<th>Control 1 year</th>
<th>Treatment baseline</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>21.85 (6.81)</td>
<td>22.60 (6.97)</td>
<td>18.45 (10.54)</td>
<td>20.3 (8.5)</td>
</tr>
<tr>
<td>Grade 2</td>
<td>39.09 (8.65)</td>
<td>39.55 (8.59)</td>
<td>35.32 (11.06)</td>
<td>36.9 (8.5)</td>
</tr>
<tr>
<td>Grade 3</td>
<td>50.03 (7.75)</td>
<td>50.17 (10.51)</td>
<td>42.86 (12.18)</td>
<td>46.0 (10.8)</td>
</tr>
</tbody>
</table>

We calculated that a ‘normal year of learning’ from Grade 1 to Grade 2 was 36.9 – 20.3 = 16.6 EGMA points, while a ‘normal year of learning’ from Grade 2 to Grade 3 was 46.0 – 36.9 = 9.1 EGMA points. Considering 12 months for an academic year, this resulted in EGMA score adjustment by 1.4 points and 0.76 points per month (adjusted to March) for shifts from Grade 1 to and Grade 2 to 3, respectively.

A ‘difference in difference’ design

To establish whether there were factors at play in the Ekurhuleni district which were influencing EGMA attainment in general, we considered the EGMA attainment data for learners randomly drawn from the control group schools which were measured over one academic year.
Whether participation in the Jumpstart intervention made a difference in learner mathematics competency, was determined by comparing the mean EGMA scores of learners in the control schools to their counterparts in the treatment schools. In addition, we compared the EGMA mean scores by grade level of learners in the treatment schools, to grade level attainment in the same schools prior to the intervention (at baseline).

To establish whether the observed differences between the means were statistically significant or not, we used a t-test. To reflect on the size of this difference, we calculated the effect sizes, employing the Cohen’s D co-efficient to estimate the impact of the Jumpstart intervention on Foundation Phase learners in the Ekurhuleni District.

**Discussion and findings**

**Comparing EGMA attainment by Grade in the treatment and control groups**

The mean EGMA results by grade in the control schools were remarkably consistent over one academic year, as shown in Table 6. The learner attainment clearly distinguished learners by Grade level, and what was found at baseline and was replicated one year later.

To explore this further, we calculated the effect that one academic year had on the control school results at Grade 2 and Grade 3 levels. T-tests confirmed that there was no significant difference between the mean values at Grade 2, t(232) =0.37, p=0.7; or Grade 3, t(322) = 1.33, p=0.18). We could, therefore, assume that there were no district-wide factors impacting on learning attainment.

We then considered the EGMA mean attainment by grade level for the learners drawn from the treatment schools compared to control schools, as summarised in Table 6.

**Table 6: Snapshot of EGMA mean raw scores for treatment and control schools**

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Baseline</td>
</tr>
<tr>
<td>Grade 1</td>
<td>18.46 (10.34)</td>
<td>24.13 (7.44)</td>
</tr>
<tr>
<td>Grade 2</td>
<td>33.11 (11.06)</td>
<td>39.66 (8.59)</td>
</tr>
<tr>
<td>Grade 3</td>
<td>42.86 (12.18)</td>
<td>51.46 (8.76)</td>
</tr>
</tbody>
</table>

At the baseline, the control schools had a higher EGMA mean for all Grade levels, compared to the treatment schools. This is to be expected as the group of control schools included Quintile 4 (fee-paying) schools, while the treatment group was drawn only from no-fee schools (Quintiles 1-3).
In contrast, in the treatment schools after 1 year of intervention, there was a statistically significant difference in the mean EGMA results by grade. T-tests confirmed that there were significant differences between the mean values of the treatment schools at baseline and then 1 year later at Grade 2, \( t(975) = -14.1, p<0.01 \); and at Grade 3, \( t(831) = -13.96, p<0.01 \). Calculating Cohen’s D resulted in large effect sizes of 0.62 SD and 0.63 SD for Grade 2 and Grade 3 learners respectively.

**Changes evident over time (after 1, 2 and 3 academic years of JumpStart intervention) in the cross-sectional performance by grade in treatment schools**

We used the repeated cross-sectional data to reflect on EGMA attainment trends over time in the control and treatment schools. (Figure 1).

*Figure 1: EGMA mean raw scores for treatment and control schools*
There were clear improvements in the EGMA mean attainment as JumpStart was embedded in each school, and learners had the benefit of multiple years of intervention. The highest mean attainment by grade level was evident after 3 years of JumpStart intervention.

Compared to their own ‘treatment baseline’, after 3 years of JumpStart intervention in treatment schools the Grade 1 intake had improved by 0.6 SD, the Grade 2 attainment had improved by 0.8 SD, and the Grade 3 attainment in the core EGMA assessment had improved by 0.9 SD. While the treatment EGMA attainment started out below the control school attainment, after 1 year of JumpStart intervention the treatment schools had caught up to the control school attainment. This gain was sustained after 2 years, and after 3 years further improvements – to surpass the EGMA attainment of the control schools - were evident.

Considering changes over time, one can also follow cohorts of learners in the treatment schools, over four years, as shown in Table 7.

Table 7: Cross-sectional data of EGMA mean raw scores in treatment schools over time

<table>
<thead>
<tr>
<th>Mean (SD)</th>
<th>Treatment baseline</th>
<th>Treatment 1 year</th>
<th>Treatment 2 years</th>
<th>Treatment 3 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 500; 438; 316; 146)</td>
<td>18.46 (10.34)</td>
<td>24.13 (7.44)</td>
<td>22.04 (6.97)</td>
<td>24.64 (7.44)</td>
</tr>
<tr>
<td>Grade 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 479; 520; 428; 150)</td>
<td>33.11 (11.06)</td>
<td>39.66 (8.59)</td>
<td>38.86 (8.59)</td>
<td>44.55 (8.95)</td>
</tr>
<tr>
<td>Grade 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 441; 516; 436; 149)</td>
<td>42.86 (12.18)</td>
<td>51.46 (8.76)</td>
<td>51.74 (10.51)</td>
<td>53.83 (10.51)</td>
</tr>
</tbody>
</table>

This can be compared to the cross-sectional data for the control schools which gives EGMA raw score means per grade, as shown in Table 8.

Table 8: Cross-sectional data of EGMA mean raw scores in control schools over time

<table>
<thead>
<tr>
<th>Mean (SD)</th>
<th>Control baseline</th>
<th>Control 1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 358; 176)</td>
<td>21.85 (6.81)</td>
<td>22.60 (6.97)</td>
</tr>
<tr>
<td>Grade 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 154; 170)</td>
<td>39.09 (8.65)</td>
<td>39.55 (8.59)</td>
</tr>
<tr>
<td>Grade 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(n = 172; 175)</td>
<td>50.03 (7.75)</td>
<td>50.17 (10.51)</td>
</tr>
</tbody>
</table>

The first Grade 1 cohort in treatment schools (M = 18.46, SD = 10.34) started below the Grade 1 cohort in the control schools (M = 21.85, SD = 6.81). When these treatment learners were in
Grade 3 (M = 51.74, SD = 10.51), they had caught up with the Grade 3 learners in the control schools (M = 50.03, SD = 7.75), and surpassed them (+1.71 EGMA points).

The second Grade 1 cohort in treatment schools (M = 24.13, SD = 7.44) started above the Grade 1 cohort in control schools (M = 21.85, SD = 6.81). When these treatment learners were in Grade 3 (M = 53.83, SD = 10.51), they had widened their advantage, compared to the Grade 3 learners in the control schools (M=50.03, SD = 7.75) attaining on average +3.66 EGMA points).

The extent of the improvements in Grade 2 and Grade 3 is measurable in standard deviations (using Cohen’s D). Effect sizes can be calculated by comparing mean EGMA attainment in treatment schools against the baseline in control schools, and then against their own baseline in treatment schools as shown in Table 9.

**Table 9: Effect sizes (Cohen’s D) over time**

<table>
<thead>
<tr>
<th>Effect size: Treatment against baseline of control schools</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>At baseline</td>
<td>–0.36</td>
<td>+0.64</td>
</tr>
<tr>
<td>After 1 year</td>
<td>+0.01</td>
<td>+0.16</td>
</tr>
<tr>
<td>After 2 years</td>
<td>–0.02</td>
<td>+0.04</td>
</tr>
<tr>
<td>After 3 years</td>
<td>+0.61</td>
<td>+0.41</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect size: Treatment against baseline of treatment schools</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 1 year</td>
<td>+0.41*</td>
<td>+0.63*</td>
</tr>
<tr>
<td>After 2 years</td>
<td>+0.31*</td>
<td>+0.25*</td>
</tr>
<tr>
<td>After 3 years</td>
<td>+0.89*</td>
<td>+0.98*</td>
</tr>
</tbody>
</table>

Comparing the treatment school attainment to the baseline control school attainment, we see that the Grade 2 learners in the treatment schools, are 0.36 SDs behind the control schools. The Grade 3 learners in the treatment schools are even further behind, by 0.64 SDs. After 3 years, the Grade 2 and Grade 3 learners in the treatment schools had a learning advantage of 0.61 SDs and 0.41 SDs, respectively, compared to their control school counterparts.

Comparing the treatment schools to their own treatment baseline, their improvements over time are more stark. Grade 2 learners in the treatment schools who have benefitted from JumpStart intervention for 2 years, are 0.89 SDs ahead of the Grade 2s in the same schools, 3 years prior. The Grade 3 learners in the treatment schools, who have benefitted from the JumpStart intervention for 3 years, are 0.98 SDs ahead of their Grade 3s assessed in the same schools, 3 years prior.
The treatment baseline is drawn from the same school as the subsequent treatment assessments, thereby overcoming the problem of the control schools being higher performing at the outset. As a result, we use these effect sizes (marked with *) to report the overall impact of the JumpStart intervention over time.

**Conclusion**

This paper may be of interest to department officials looking for interventions which have impact at scale, as well as researchers seeking to utilise the EGMA in SA settings. It contributes to the mathematics literature on intervention studies in three ways.

Firstly, this study offers a benchmark of the Ekurhuleni district in Gauteng, for attainment in EGMA, by grade level (see Table 7). While Platas et al. (2014) offer an EGMA toolkit, this does not include normed data. They argue that the different country contexts, mitigate against such. While not done in a random selection of schools, this study offers a benchmark for a particular district, which may then be used to compare to other districts, or interventions (and reasons for differences explored).

Secondly, the paper contributes impact research findings on another SA intervention to improve mathematics at the FP. This study found that the JumpStart intervention made a statistically significant difference to the attainment of learners in the EGMA assessment, as measured in raw scores on the test.

Thirdly, this study offers another benchmark of effect size for early grade mathematics in mathematics in SA. For ease of reference the effect sizes are consolidated in Table 10.
### Table 10: Effect sizes of SA early grade mathematics interventions

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Focus</th>
<th>Average effect size</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>JumpStart after 3 academic years</strong></td>
<td>Mathematics Grades 2 – 3</td>
<td>0.89 – 0.98 ≈0.94</td>
<td>This study</td>
</tr>
<tr>
<td>Improve teaching quality: pedagogical interventions</td>
<td>General</td>
<td>0.92</td>
<td>Conn (2017)</td>
</tr>
<tr>
<td><strong>JumpStart after 1 academic year</strong></td>
<td>Mathematics Grade 1 – 3</td>
<td>0.41 – 0.63 ≈0.52</td>
<td>This study</td>
</tr>
<tr>
<td>Gauteng Primary Literacy and Mathematics Strategy (GPLMS) after 1 academic year</td>
<td>Mathematics Grades 1 – 3</td>
<td>0.35-0.61 ≈0.48</td>
<td>Fleisch et al. (2016)</td>
</tr>
<tr>
<td>GPLMS after 2 academic years</td>
<td>Mathematics Grades 1 – 3</td>
<td>0.5</td>
<td>Fleisch et al. (2016)</td>
</tr>
<tr>
<td>Improve teaching quality: instructional time interventions</td>
<td>General</td>
<td>0.46</td>
<td>Conn (2017)</td>
</tr>
<tr>
<td><strong>JumpStart after 2 academic years</strong></td>
<td>Mathematics Grades 2 – 3</td>
<td>0.31 – 0.25 ≈0.28</td>
<td>This study</td>
</tr>
<tr>
<td>R-Maths intervention in WCED</td>
<td>Mathematics Grade R – 1</td>
<td>0.2</td>
<td>Hazell, Spencer-Smith &amp; Roberts (2019)</td>
</tr>
<tr>
<td>Remedial education</td>
<td>Mathematics</td>
<td>0.19</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>Teacher-level structured pedagogy interventions.</td>
<td>Mathematics</td>
<td>0.14</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>Merit-based scholarships</td>
<td>Mathematics</td>
<td>0.11</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>School feeding</td>
<td>Mathematics</td>
<td>0.10</td>
<td>Snilstveit et al. (2015)</td>
</tr>
<tr>
<td>Extra time in school</td>
<td>Mathematics</td>
<td>0.09</td>
<td>Snilstveit et al. (2015)</td>
</tr>
</tbody>
</table>

After 1 academic year the JumpStart intervention shows a learning gain of approximately 0.52 SDs. This is comparable to the learning gain (of ≈0.48SD) found by the GPLMS intervention after 1 academic year (Fleish et al., 2016).

Where the two interventions differ is the findings of effect size after 3 or 4 years. For JumpStart after 3 academic years, the effect had increased (to≈0.94SD), which is comparable to the expected range of general pedagogical interventions which improve teaching quality, as identified by Conn (2017) in his meta-analysis, and much higher than effect sizes reported by Snilsveit et al. (2015) in relation to mathematics specifically. This in in sharp contrast to the finding of ‘no effect’ for GPLMS after 4 academic years.

Both GPLMS and JumpStart include high quality instructional materials for mathematics. They differ in that the JumpStart model, which includes employing interns with tablets to monitor learner progress and limited teacher training, while the GPLMS model offers teacher training and school-based mentoring. The higher and sustained effect of the JumpStart intervention after 3 years may be a result of its smaller scale. However, its findings over three years, suggested that JumpStart may hold more long term promise than the GPLMS model which applied the education triple cocktail. While teacher training and school-based mentoring show impact for 2 academic years in GPLMS, this had disappeared by the fourth year. We conjecture
that the JumpStart intern model and real time formative assessment analytics ensured the fidelity of the intervention and facilitated greater improvements over time, than was possible in GPLMS.

References


A CASE STUDY ON RESPONSES TO INTEGER ITEMS: A CHANGE IN ERRORS FROM GRADE 9 TO GRADE 10
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Abstract

We report on changes in learners’ performance and their errors with negatives and subtraction as they progress from the beginning of Grade 9 to the end of Grade 10. Using the same test instrument, a cohort of 60 learners in one school in Johannesburg was tracked and tested twice in both years. Using a mixed-methods approach, we explore the extent to which learners’ performance improves on items relating to negative numbers and subtraction. Findings suggest that the ability of learners to use negative numbers and to subtract improve, but only in Grade 10. Findings also suggest that in Grade 9 learners struggle more when there are brackets in the item, and in Grade 10, learners operate more often with negatives.

Introduction

Making sense of negative numbers was difficult for the pioneers of the field of mathematics (Bishop, Lamb, Philipp, Whitacre, & Schappelle, 2014) and it continues to be a topic that is both difficult to teach and learn (Ball, 1993). Previous research has identified common errors that learners make with negatives numbers (Gallardo and Rojano (1990); Kieran (1992); Vlassis (2004)) but literature has not reported on the progression (or degeneration) of learners’ procedural competencies. This paper investigates performance with negative number amongst Grade 9 and 10 learners, using longitudinal data. We identify common errors and investigate how the errors change from Grade 9 to Grade 10. This mathematical content is not explicitly the object of learning in the Grade 9 or 10. This is because it is covered, and presumably mastered, in Grade 8. However, in reality we find that learners at Grade 10 level are still not mastering negative numbers. Being flexible in dealing with negative numbers is an important ability to have, as it infiltrates all other mathematics topics. It seems reasonable to assume that poor performance in working with integers may result in poor performance in other topics. The research question that guide this study is:

What errors are made on integer items and how do they change from Grade 9 to Grade 10?

The research reported here forms part of a larger study in which the first author investigates learners’ responses to solving linear equations and possible links with errors on other test items including integer items. This paper focuses on performance on the integer items and investigates the change in performance from Grade 9 to Grade 10. The analysis consists of three parts:

1. Distribution of learners’ test scores and integer scores.
2. Overall integer performance in relation to the test
3. Error analysis
Literature review

We take a socio-constructivist perspective on learning where errors are embraced and seen as opportunities for learning (Nesher, 1987). Drawing on Nesher’s (1987) view of errors as rational and rooted in some (mis)understanding of prior knowledge and we adopt the view that errors are “normal and necessary” (Brodie, 2014, p. 221)

There is much literature on analysing learners’ mathematical errors, especially on the nature of learners’ errors and possible reasons for their underlying misconceptions (see for example: Borasi (1987); Godden, Mbekwa, and Julie (2013); Nesher (1987); Olivier (1989)). The literature mentioned above is evidence that analysing learners’ errors has been of great interest to the mathematical community for many years and therefore this inquiry adds to an important area of mathematics education research. Another important reason for studying learners’ errors is for their pedagogical implications (Corder, 1982). Mathematical errors can provide valuable insights into a learner’s thinking, which can be used productively in teaching (Brodie, 2014). Research can inform teachers on how teaching can be altered and which tasks could be designed to attend to the problems that the error analysis helps to diagnose (Hiebert & Carpenter, 1992).

Research shows that learners make many errors when dealing with negative numbers (Gallardo & Rojano, 1990; Pournara, Hodgen, Sanders, and Adler (2016); Schindler, Hußmann, Nilsson, & Bakker, 2017); Vlassis (2004)). There are three factors/conceptual challenges that may lead to learners’ errors with negative numbers. These are: the cardinality and ordinality of numbers; the abstract nature and lack of concrete association of negative numbers; and lastly the three functions of the minus symbol. Each of these is discussed below.

1) Cardinality and ordinality
An understanding of number involves understanding both cardinality and ordinality (Bishop et al., 2014). A cardinal understanding refers to magnitude and counting, which, for positive numbers, is not only familiar to learners but is concrete. Learners are able to count the number of pencils and say who has the most with positive numbers. An ordinal understanding is about direction and order in relation to zero. Learners need to know which number is smaller and which is bigger (Bishop et al., 2014). One difficulty in understanding negative numbers is that they represent both a cardinal and an ordinal context (Bishop et al. (2014). This means that a negative number in itself tells you it’s cardinality, that it is a negative value but the minus symbol tells us its position in relation to zero at the same time. Research has shown that errors made with negative numbers and the mathematically correct order relation is largely due to learners’ “out-of-school” experiences (Schindler et al., 2017). Meaning that learners enter the classroom with prior knowledge that if numbers are ordered from smallest to largest, then the list would start with one, two, three, etc. When learners encounter negative numbers they still see the smallest value as being (negative) one. A common error found when ordering or comparing negative numbers was focused on “absolute values, probably drawing on prior experiences with natural numbers, disregarding the negative signs of the numbers” (Schindler et al., 2017, p. 488).
Abstract numbers: lack of concrete association

Another reason negatives are difficult to understand is due to the inability to represent negative numbers with concrete objects. In the concrete operational stage of development, developing number sense as a one-to-one correspondence: ordinality, and then the cardinality of set (Piaget, 1964). However, when encountering negative number, learners struggle to make these tactile one-to-one correspondences and model a set with concrete manipulatives (Herscovics & Linchevski, 1994). An example of a concrete manipulatives is the integer chips (Battista, 1983 #415) where red chips represent negatives and yellow chips represent positives and a pair of red and yellow create zero. Although this is an example of a concrete manipulative a red chip is still tactile and concrete and only stands for a negative number, it is not possible to physically represent a negative value.

2) Multiple meanings of the symbol ‘−’

Some errors stem from learners not being flexible with the different functions of the minus symbol (Vlassis, 2004). Gallardo and Rojano (1990) argue that the minus symbol has three different functions: unary, binary and symmetric and it is therefore not surprising that, learners produce many different errors. The three functions of the minus symbol are discussed below.

Triple function of the minus symbol

a) Unary function
The unary function of the minus sign is largely about the formal definition and understanding of negative numbers. It is where the minus sign is referred to as a “structural signifier” (Vlassis, 2004, p. 472). For example, considering the value −5, the ‘−’ in front of the 5 is a sign that identifies 5 as a negative number rather than subtracting 5 from another value. This is evident in, for example, solutions such as \( x = -5 \) or in an expression, for example \( -5 + 4 \) which is read as ‘negative five add four rather than subtract five add four’

b) Binary function
The binary function is where the symbol ‘−’ signifies an operation, for example in \( 13 - 8 \) where 8 is subtracted from 13. The minus sign indicates a difference between two numbers which requires an action and is referred to as an “operational symbol” (Vlassis, 2004, p. 472).

c) Symmetric function
The symmetric function involves taking the opposite sign and is particularly important when dealing with inverses. The example below shows all three functions in a single number sentence:

\[
-4 - (-3) - 6 = -7
\]

Read as ‘negative 4’: Unary function

Read as ‘subtract negative 3’: Symmetric function

Read as ‘subtract 6’: Binary function

The result, read as ‘negative 7’: Unary function
In South African primary schools, learners’ only experience with the minus symbol is as an operation. Subtraction in number sentences such as $4 - 1 = _$ are introduced in Grade 1 (DBE, 2011c) and learners do not encounter the minus symbol performing a different function until Grade 7. In Grade 7, learners’ previous understandings are challenged when a) a negative number is to be objectified and seen in its unary function having its own cardinality and position on the number line; and b) when the binary function of the minus symbol can produce a negative number, hence including the unary function. This challenges the previously learnt strategy of finding the difference where a smaller number is subtracted from a larger number.

Learners who are not able to deal with the unary function are likely to apply the binary function instead. For example: $-10 + 6$ would be interpreted as $-(10 + 6)$ or even $10 - 6 = 4$ Vlassis (2004) reports that learners often deal with negatives (or the unary function) by inserting mental brackets around some numbers to exclude the leading negative. Gallardo and Rojano (1990) refer to this type of reasoning as bracket reasoning.

Kieran (1992) reported that learners overgeneralise this idea of “a negative and a negative make a positive” rule for multiplying integers, and apply it for example to $-6 + 5 \rightarrow (-6)(+5) \rightarrow -30$ or they multiply the symbols and add the numbers: $-6 + 5 = -11$. This reasoning is referred to by Vlassis (2004) as the signs rule. The different form of reasoning, such as the signs rule are discussed below. These are examples of incorrect reasoning identified in literature which lead to errors and are the codes I use when coding errors relating to negative number.

a) Right to left reasoning

Right-to-left reasoning (Vlassis, 2004) is used when an expression is simplified by operating from right to left. For example, when $3 - 8$ is read from right to left as $8 - 3$, the answer is 5. Vlassis (2004, p. 477) argues that learners reverse the order to make operating with the minus sign more ‘comfortable’. Although I agree with this interpretation, if the leading number is a negative number, for example $-8 + 3 \rightarrow 5$, then the same error cannot receive the same interpretation. What is possibly done with $-8 + 3 = 5$ is that the operations are reversed in order to obtain a positive answer, something more comfortable. Ryan and Williams (2007) offer an explanation for the error $3 - 8 \rightarrow 5$ in that learners seem to be overgeneralising the commutative property of addition and applying it to subtraction. So where $a + b = b + a$, learners overgeneralise this to $a - b = b - a$. This interpretation could also then be applied to $-8 + 3 \rightarrow 5$, which produces the same incorrect answer when the values are swapped around, for example $3 - 8 \rightarrow 5$. It is important to note that in primary school arithmetic, learners work with positive numbers and so subtracting a larger value from a smaller one does not make sense to them. Reasoning from right to left and overgeneralising the commutative property of addition therefore produces errors that are understandable. These types of errors are discussed in literature (Ryan & Williams, 2007) and are prevalent in our data.
b) Detachment
When there are multiple terms in an expression, for example, $2x - 4 + x - 2$, Vlassis (2004) argues that learners may re-group the like terms but do not focus on the operations and leave the signs in their original place. For example, the expression $2x - 4 + x - 2$ is reduced to $(2x - x) + (4 - 2)$ where the $x$ and the 4 swap places so that the like terms are together. This error could be explained by learners overgeneralising the commutative property for addition but also by overgeneralising the associative property for addition and ignoring the operation. For the associative property, different groupings of addition do not affect the result, for example: $a + (b + c) = (a + b) + c$. Herscovics and Linchevski (1994) term this error detachment of the minus symbol. I however have items with only two terms and hence have redefined detachment to suit my data. I use it in the sense that learners detach the minus symbol and add what remains, only to re-attach at the end. For example, $7 - 5 \rightarrow (-)7 + 5 \rightarrow -12$. It is as if the learner ‘hold’ the minus symbol in their head, add the numbers as though they are both positive and then finally reattach the symbol. We specifically decided that the operation the learners must apply is addition because if they are detaching a minus symbol and not operating with it they are in a way, ignoring it’s existence. With this error, learners do not have the signs in focus.

c) Bracket reasoning
Bracket reasoning (Vlassis, 2004) is characterised by inserting brackets (explicitly or mentally) for example $-5 + 3 \rightarrow -(5 + 3) \rightarrow -8$. The minus sign is detached from the 5 and the numerals 5 and 3 are operated on. This is therefore a special case of detachment. The difference is the items structure has a leading minus symbol. Ryan and Williams (2007) argue that learners view the signs and numbers as separate objects meaning that they see all numbers as positive with different symbols in between each number. This could explain why learners operate on the numbers and then re-attach the symbol.

d) Signs rule reasoning
Another form of reasoning offered in the literature is where there is an explicit focus on the operations. The error made with this form of reasoning is characterised by overgeneralising the signs-rule (Gallardo & Rojano, 1994; Vlassis, 2004), i.e. the multiplication rule for integers: *a negative and a negative make a positive and a negative and a positive make a negative*. The learners use the product of the multiplication of signs as the sign of their answer, however, what the learners do in terms of an operation is not made clear in the literature. Do learners then add the numerals, or subtract? Or do they obey the given operation? Or do they use the sign as the operation as well. Because of this ambiguity, we decided to redefine the signs rule to be the multiplication of the signs and using the product as the operation as well. This decision was made because any other variation would compete with other errors, for example $-7 + 5 \rightarrow -12$. Here
obtaining 12 could be from bracket reasoning or from multiplying the signs (-) and then obeying the operation (7+5). Our decision avoids dual reasoning except for one instance: \(-7 - 5 \rightarrow 12\). Twelve could be obtained by detachment or by our definition of the signs rule. Our decision regarding this ambiguity was to preference the sins rule as it is in literature (we only narrowed down the definition) rather than use detachment because it is an error that was completely redefined by the authors. When making the sins rule error learners are not distinguishing between the sign and the operations.

e) Too many signs reasoning
Gallardo and Rojano (1994) identify an error where learners deliberately leave out (or ignore) certain minus symbols. They provide the example of a learner reducing \(-a - (\text{−}b)\) to \(−a − b\) because the minus symbol in the bracket, attached to b, “is not required” (p. 162).

**Methodology**

This study is part of a larger study, The Wits Maths Connect Secondary (WMCS) project. They offered a professional development (PD) program, from 2010-2019 that aimed at improving both the quality of mathematics teaching as well as teachers’ mathematical knowledge. The sample used in this study is a cohort of 60 learners from one school. This sample was chosen purposefully as it is a school where 67% of their teachers participated in the PD offered by WMCS. In addition, there were only 60 learners who could be traced from Grade 9 into Grade 10, making this sample unique. In addition to being a unique subset of the WMCS data, this school is one of the 14 phase 1 schools of specialisation\(^4\) that focus on Mathematics, Science and ICT. It is a quintile 4 school and has a teacher/learner ratio of 1:30. The Grade 12 learners in 2017 obtained a 97.2% pass rate, with 58.4% Bachelors pass. The sample used here is therefore a purposively selected sample of learners from one school who had four data points. These learners wrote the same test at four points over two years: twice in Grade 9 (a pre and post-test) and twice in Grade 10 (a pre and post-test). Because the Grade 9 learners are the same learners in Grade 10, a one-way repeated ANOVA can be conducted. Learners’ responses where initially coded and captured on a spreadsheet as correct, incorrect, or missing. For each test, the total number of correct responses per learner (learner scores) and the total number of correct responses per item (item scores) were calculated. Learners responses to six items relating to negative numbers were coded using Gallardo (2002), Vlassis (2004). The error codes are different to coding of correct, incorrect and wrong in that incorrect responses are now analysed and categorised into error categories. Both descriptive and inferential statistics were conducted to explore learners’ progression in negative numbers. For the purpose of this paper only items 1 and 3c are discussed.

\(^4\) Introducing schools of specialisation is an initiative prompted by the Gauteng Department of Education. These schools are a response to the cities' plan for transformation, modernisation and reindustrialisation of Gauteng. The intension is for these schools to be a catalyst for the future of basic education, addressing the skills shortage and extending learner opportunities within the system and post matric.
Item 1: Write these numbers in order from smallest to largest:
30; −35; −2; −500; −10; 4

When coding the responses to Item 1, three codes were used: if the numbers were place in order as if they were all positive, for example -2; 4; -10; 30; -35; -500, then the response was coded as absolute value (abs). If the positive numbers were ordered correctly but the negative values were ordered from largest to smallest, for example -2; -10; -35; -500; 4; 30, then the responses were coded as negative reversed (neg rev). All other responses that were not absolute value or negative reversed were classified as other.

Item 3c: −5 + 7

There were 4 types of incorrect responses to this item; −2; 12; −12 and other responses (for example: 1; 4; 23)

Too many signs (Vlassis, 2004) were assigned to the response 12 because the learners ignore all the minus symbols and add.

The signs rule was the code given to the response of -2. This is because the multiplication of the two signs yield a negative (the sign of the answer) and then subtraction is the operation used.

Bracket reasoning was the code given to the response -12. This is because the learners detach the leading negative and operate on the remaining numbers and operations.

This study is a mixed methods study that consists of two phases, the first being a quantitative analysis on the performance of learners in relation to the test as a whole. This is done to see where integers fit in with all the other topics. For phase 2, an in-depth error analysis is conducted to determine the errors made and how they change as learners move into Grade 10.

Findings and discussions

As mentioned earlier, our analysis consists of three parts:

1. Distribution of learners’ test scores and integer scores.
2. Overall integer performance in relation to the test
3. Error analysis

Part 1: Overall integer performance in relation to the test

In this section, I compare the distribution of learner scores to the distribution of learners’ performance in integer items. I use Box Plots and an ANOVA test to show that there are significant improvements between each of the four tests, but that in relation to integers the improvement is in Grade 10 and not in Grade 9.

a) Comparison of the distribution of learner scores to the distribution of learner’s performance in integer items

The distribution of learners’ scores is as expected in that the mean increases by 11 percentage points (p.p.) from 27% to 38% in Great 9; and then increasing by 4p.p. to the beginning of Grade 10 and finally increasing 10p.p. to 52%. This means that from the beginning of Grade 9
to the end of Grade 10, learners’ mean scores improve by, on average, 25p.p., which is a 93% increase. Even though this seems impressive, it is alarming that as learners are preparing to enter Grade 11, their average score is 52% on a mathematics test set with Grade 8 and 9 curricula items.

The Box Plot (see figure 1) shows the distribution of the learners’ scores as a percentage. There is one plot for each group/test: The Grade 9 pre-test; Grade 9 post-test; Grade 10 pre-test and Grade 10 post-test. Box plots are an effective way of visualising the differences amongst different groups. They typically give a visual representation of min, max, quartile 1, median and quartile 3, but can include additional information, such as outliers and the mean. The cross in each box represents the mean and the horizontal line, the median. There is only one outlier in the Grade 9 Pre-test. Unsurprisingly the mean increase in every test: by 11% within Grade 9; 4% between Grade 9 post and Grade 10 pre and 10 % in Grade 10. Even though the greatest improvement appears to be within Grade 9 and within Grade 10 (according to the mean), the increase in the upper quartile and median from Grade 10 pre to Grade 10 post suggests a more significant improvement in Grade 10. The improvement from Grade 9 Pre to Grade 10 Post, with more than 75% of the learners performing better than their average Grade 9 pre-test score, suggests a significant improvement over the two years.

![Distribution of Learner scores](image)

**Figure 1: Distribution of learners’ test scores**

Although these appear to be significant improvements, inferential statistics can confirm (or refute) this observation. Therefore, a one-way repeated measure ANOVA was conducted to compare the scores of the algebra test written at the 4 points over 2 years. Point 1: Grade 9 pre-test written in February 2017; Point 2: Grade 9 post-test written 7 months later, in September 2017; Point 3: Grade 10 pre-test written 4 months later, in February 2018; and lastly, point 4: Grade 10 post-test written 7 months later in September 2018. There are many forms of analysis of variance tests (ANOVA). These tests allow one to statistically test whether participants perform the same or differently in different conditions or at different times. I used a repeated
measures ANOVA instead of a One-Way ANOVA because the groups are directly related. They are the same group of 60 learners. Using a Greenhouse-Geisser correction (Tanner, 2012), it was determined that there was a steady and significant statistical increase from one measure to the next with a large effect size: Wilks’ lambda=0.35; F(3,57)=35.3; P < 0.005; \( h_p^2 = 0.65 \). Not only is there a statistically significant improvement from one test to the next, but the pairwise comparisons shows a statistically significant improvement and interaction between all 4 tests- including between Grade 9 post and Grade 9 pre-test which with only a 4% increase didn’t appear to be significant. This means that what we observe in the data cannot be attributed to chance.

b) Distribution of integer scores
Knowing that there was a significant improvement in the learners’ overall test scores, we looked at the distribution of integer scores across the tests. There was no difference in the Grade 9 pre and Grade 9 post-test integer scores, but there was a difference from Grade 9 post to Grade 10 pre-test and from Grade 10 pre to Grade 10 post-test. The mean scores for each test are: 41%; 43%; 53% and 68% for the Grade 9 pre, grade 9 post, Grade 10 pre and Grade 10 post-test respectively (See figure 2). Even though the mean increases by 2p.p in Grade 9, it appears that the improvement in integer items occurs as learners reach Grade 10 and during Grade 10. We see from the Grade 10 pre-test upper quartile that 50% of learners in Grade 10 were achieving better than 75% of what the learners achieved at the end of Grade 9. In addition, by the end of Grade 10, 75% of the learners were performing better than what 50% of them did in Grade 9 and 50% of them performed better than what 75% of learners performed at the beginning of Grade 10. Again, a repeated measure ANOVA was conducted to compare the scores of the integer items over the two years and provides evidence that the improvement we saw in the box plots, was indeed significant and not due to chance. Using a Greenhouse-Geisser correction, it was determined that there was a steady and significant statistical increase and a large effect size (Wilks’ lambda=0.69; F(3,82)=12.19; P<0.005; \( h_p^2 = 0.31 \)) between 3 of the four tests. This confirms that learners only improved in integer items from the end of Grade 9 to the end of Grade 10 and that during Grade 9 there was no statistically significant improvement. This is possibly due to the fact that at the time of testing the Grade 9 learners had recently revised negative numbers.
Part 2: Overall integer performance in relation to the test

In part 2 I look at where integers fit in with the other items in relation to performance. I use line graphs to show that the use of integers does not appear to improve in Grade 9 but that the improvement comes in Grade 10. The topic that makes the most improvement in Grade 9 is related to expressions.

Knowing that there were significant improvements across all four tests, we investigate how learners performed on each item, rather than on the test as a whole. Figure 3 shows the change in correct responses from Grade 9 Pre to Grade 9 Post. The main take away that this graph provides is that there is very little difference in the integer items (circled section). The section that did improve the most was related to expressions and equations.
Since the number of correct responses to the integer items (items 3a-3f) did not increase very much, it is possible that in Grade 9 learners improve in dealing with addition of letters but continue to struggle with negative numbers as well as negated variables. In contrast to the finding during Grade 9, the learners’ performance in Grade 10 are quite different. In Grade 10 learners’ gains are with the integer items (See figure 4).

This improvement corroborates the sense that the main learning in Grade 10 is attributed to negatives but in Grade 9 to letters. The hypothesis suggests that negative numbers make more sense to learners towards the end of Grade 10 despite the fact that this is a topic introduced in Grade 7.
Part 3: Error analysis of Items 1 and 3c

Conducting an error analysis is important in this context as we are able to see shift (in any) in the errors made. Item 1: Write these numbers in order from smallest to largest. 30; −35; −2; −500; −10; 4 is an item that was answered correctly by many learners in all four tests. One could argue from a qualitative perspective that the item is so easy that it does not provide us with any useful information about learners’ performance. The beauty of a mixed methods analysis is that sometimes we are able to see something useful by using a different lens. Besides a correct response, the two most common responses to ordering integers was a) −2 4 −10 30 −35 −500, which we termed “absolute value”, and b) −2 −10 −35 −500 4 30, which we termed “negative reversed”. Literature has shown that in understanding number in general one needs to have a cardinal understanding as well as an ordinal understanding of number (Bishop et al., 2014). A cardinal understanding refers to magnitude and counting, which for positive numbers is not only familiar to learners but it is concrete. The magnitude of a negative number the one of the first abstract ideas a learner will encounter before algebra. An ordinal understanding requires learners to be able to order numbers, knowing which is smaller and which is bigger. Besides needing both a cardinal and ordinal view of number, literature has shown that learners also need a tri- understanding of the minus symbol (Vlassis, 2004), making negative numbers particularly difficult to learn. It appears that learners who made the absolute value error detached the minus symbol, unable to view the negative number in its unary function and then order the numbers as though they were all positive, only to reattach the minus symbol in their written solution. Learners who made the reverse negative error appear to be able to view negative numbers as different to positive. Possibly having a cardinal and unary appreciation of the number but is unable to order negative numbers correctly. In Grade 9 (both the pre and post-test) the most common error is the absolute value error, but in Grade 10 (pre and post-test) the most common error is the negative reversed. This suggests that learners move from not viewing a negative number in its unary function towards having a unary but not an ordinal understanding. This also suggests that a negative reversed error is a “better error” than an absolute value error.

Figure 5: Responses to item 1
There were three incorrect responses to item 3c: −5 + 7 → 12; −5 + 7 → −12 and −5 + 7 → −2. In Grade 9, -12 was the most common answer but by the end of Grade 10 the most common error was -2. We see a steady decrease in the response, -12, but a steady increase in the response -2 from the Grade 9 post-test to the end of Grade 10. A possible reason for the response -12 is bracket reasoning (Vlassis, 2004), or alternatively known as detaching of the minus symbol (Linchevski & Herscovics, 1996). Learners treat -5+7 as – (5+7), detaching the minus symbol, unable to view -5 in its unary function, and operating on what feels ‘comfortable’ and results in a positive answer. The answer of -2 however could be attributed to the overgeneralising of the signs rule. In -5+7, leaners would say the negative (from 5) and the positive (from 7) make a negative. This ‘negative’ then appears to be both the sign and the operation resulting in -2. A common thread from item 1 and 3c’s errors is that in Grade 9, the learners from this school appear more prone to detach the sign and not operate on or with it, but in Grade 10 they seem to be more willing to operate with a negative.

**Conclusion**

The error analysis presented here showed how in Grade 9 learners are more susceptible to detach the minus symbol but in Grade 10 more learners are operating with the negative. Preliminary results show that although there are more learners getting more items correct, and the test performance is statistically significant, they appear not to be learning, or improving very much in Grade 9 from one test to the other in integer items. Results show that the gains in integers happen in Grade 10. As mentioned before the gains that are made, although welcomed, it is surprising as after two years of needing to apply negative number manipulation one would expect that items set at grade 8 level would become ‘easier’.

**Implications for teaching**

The results of this study suggest that teachers need to place more emphasis on integer understanding in Grade 9. Integers are explicitly taught in Grade 8 but not in Grade 9. The fact that learners are taking an extra year to become familiar with integers suggests that they need more practice and engagement with integer items.

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EXPLORING CHALLENGES EXPERIENCED BY TEACHERS TEACHING NUMBER SENSE IN THE FOUNDATION PHASE
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Abstract

Early number sense includes learned skills that involve explicit number knowledge. Teachers play a crucial role in developing learners' knowledge and understanding of number sense, however, most teachers experience challenges in teaching number sense in the Foundation Phase. This paper explores the challenges experienced by teachers and the calculation strategies they use to develop learners’ number sense. A qualitative case study through the constructivist theoretical lens seemed best suited for this research. The research was conducted in Gauteng with six foundation phase teachers, two from each grade in one school. Findings revealed that teachers lacked knowledge, understanding and training on how to teach number sense. Results also identified the calculation strategies teachers used to develop learners' number sense. It is recommended that teachers receive on-going professional development on content, methods and approaches to teaching number sense. Furthermore, a recommendation for DBE to collaborate with higher education institutes for support is made.

Keywords: Early number sense (ENS); strategies; Foundation Phase; mathematics; constructivism

Introduction

South Africa is faced with challenges in mathematics performance across all phases (Taylor, 2013; Fleisch 2008). The poor performance of learners in mathematics is documented in both national and international studies for example the Annual National Assessment 2011 (ANA) (DBE, 2011a) and the Trends in International Mathematics and Science Study 2008 (TIMMS) (Mullis, Martin & Fay 2008). According to DBE (2011a), poor learner performance is due to numerous challenges. Most learners are not performing as expected in national and international assessments to meet the demands of the 4th Industrial Revolution. Tsao and Lin (2012) state that much research was done with students understanding of number sense and very few on what teachers understand and teaching practice about number sense. In a comparative study by Carnoy and Chisholm (2008), the low performance of foundation phase learners in mathematics is reflected in teachers’ competencies to teach mathematics (Moloi & Chetty, 2010). According to Courtney-Clarke and Wessels (2014), learner performance is associated with teachers’ subject knowledge and their confidence influences how they teach. Anamuah-Mensah, Mereku and Ghartey-Ampiah (2008) agree that the mode of delivery of mathematics has an impact on learner performance.

The poor performance in mathematics and the strategies teachers use to develop learners’ number sense is of concern to educationist across the country (Tsao & Lin, 2012; Way, 2011). According to DBE, (2011b) and Martin and Mullis (2013) most learners are lagging in
mathematics due to a lack of knowledge and understanding of number sense. Teachers may have the content knowledge to teach number sense; however, they lack the pedagogical content knowledge (Tsao & Lin, 2012; Shulman, 1987). DBE (2011a) found that the methods and approaches teachers use are often inappropriate or ineffective for the foundation phase.

The purpose of this study was to explore the challenges experienced by teachers teaching number sense in the foundation phase and what calculation strategies they use to develop learners’ number sense. The following research questions were formulated: (i) What challenges do Foundation Phase teachers experience in teaching number sense? (ii) What calculation strategies do teachers use to develop learner’s number sense?

**Literature Review**

**Explanation of number sense**

'Number sense' has gained much interest by researchers in mathematics education, mathematical cognition and special education (Whitacre, Henning & Atabas, 2017). In their research, they found that authors have noted difficulties in defining 'number sense.' These authors have described three "number sense" constructs namely, 'Innate numbers sense (INS)'; 'Early number sense (ENS)' and 'Mature number sense (MNS)'. For this article the focus is on ENS which includes "learned skills that involve explicit number knowledge, such as counting items using number words and comparing numbers represented symbolically as a numeral," (Whitacre, Henning & Atabas, 2017: 205). Dyson, Jordon and Glutting (2011) agree that ENS is an essential predictor of success in school mathematics, especially in the early childhood years. Cheung and McBride-Chang (2015) state that learners’ levels of ENS skills vary and are influenced by education and their experiences in early childhood. An intuitive sense of number begins at a very early age; learning to count with understanding is a crucial number skill. Van de Walle, Karp and Bay-Williams (2015) and Shumway (2011) described number sense as a complex phenomenon; a person’s skill to use and recognise numbers by knowing their relative values. A sound understanding of number sense facilitates problem solving, reasoning and allows discussions around mathematical ideas (Way, 2011). According to the DBE (2011b), number sense is part of ‘Numbers, Operations and Relationships (NOR)’ and is allocated a weighting of sixty-five percent (65 %). Teachers must have a good knowledge and understanding of number sense to develop and strengthen learners’ knowledge and understanding of number sense (Naude´ & Meier, 2014).

**Importance of number sense in the early grades**

The New Zealand Government (2016) states that a child's formative experience of mathematics lays the ground for their imminent mathematics learning and success. Mathematical knowledge and skills enable learners to think logically, strategically, creatively and critically. The importance of number sense cannot be overemphasised. Number sense is a significant construct that separates the superficial level of understanding from subject mastery. According to Hornigold (2017), number sense helps learners to improve their skills and knowledge in mental mathematics and provides them with the ability to look at maths in their contexts and make comparisons. Van de Walle et al. (2015) state that good number sense helps learners to
work and manipulate numbers to make calculations meaningful and straightforward. This skill assures them to be flexible in their approach to solve mathematical problems.

Brannon, Lutz and Cordes (2006) agree that number sense is vital for young learners because it promotes confidence and encourages flexible thinking. Learners can create a relationship with numbers and use mathematical language in their discussions. According to the DBE (2011b), strong number sense helps to build a foundation for mathematical understanding. In the early grades, a solid foundation allows learners to compute and solve complex problems in later grades. Nieder (2020) believes that building a love for mathematics begins with building an understanding of numbers.

In their study, Dyson, Jordan and Glutting (2011) found that a comprehensive knowledge of number sense was a dependable and robust predictor of mathematics achievement in the later grades. Educationists agree that the development of number sense among young learners has a direct link to future mathematics achievement; just as phonological awareness has been linked to reading achievement (Kosanovich, Weinstein, & Goldman, 2009).

**Role of the teacher in teaching number sense**

Abramovich, Grinshpan and Milligan (2019) state that teachers should present math concepts, methods, and language through a range of relevant experiences and research-based teaching methods and approaches. Way (2011) agrees that teachers should aid learners in noticing the relationship of ideas within mathematics and other subjects, strengthening their mathematical knowledge throughout the teaching day and across the curriculum. Chapman (2006) argues that teachers need to monitor the way learners learn mathematics through interaction. Learners should be allowed to construct their learning. Teachers should inspire learners to share and explain their thinking as they interrelate with each other on important mathematical concepts.

Peters and Rameka (2010) state that motivation is crucial to the development of children’s early mathematical concepts. Appropriate pedagogical approaches, according to Dunphy (2009), are highly regarded in developing guidance in teaching mathematics in the Foundation Phase. Hart and Swars (2009) agree on the importance of mathematics content. To this comment, Peters and Rameka (2010) state that inappropriate teaching practices, such as rote learning in isolation, may result in learners lacking understanding of the content, therefore developing negative attitudes to mathematics.

Campbell, Ellington, Haver and Inge (2013) agree that there must be professionally trained mathematics specialists with sound pedagogical knowledge who are readily available and accessible to support schools. Research by Golafshani (2013) and Nolan (2012) found that teachers were strongly drawn towards teaching like how they were taught, instead of being creative and innovative. Tsao and Lin (2012) and Golafshani (2013) found that teachers with more inadequate content knowledge emphasised facts over understanding mathematical concepts and too often relied on textbooks over hands-on experience. It was also found that these teachers interacted less with students and expected these learners to work more individually. Barnes and Solomon (2014) state that on the other hand, teachers with a broader content knowledge tend to teach in a livelier manner, using a variety of methodologies and encouraging learners to ask questions and make comments during the lesson.
Teacher content and pedagogical knowledge

The categories of pedagogical knowledge, according to Shulman (1987), direct teachers' understanding of the comprehensive learning process. The broad expertise and objectives of education are at the fore and teachers are the driving force to understand themselves, the environment and the learners whom they are teaching. A teacher’s pedagogical content knowledge integrates the content knowledge with features of the teaching and learning process (Grimmett & MacKinnon, 1992). Teachers must have sound knowledge and understanding of the topics and content that they are teaching to their young learners (Ball, Lubienski, & Mewborn, 2001).

According to Lesch (2012), learning outcomes are statements that describe significant and essential learning that learners have achieved. The Curriculum and Assessment Policy Statements, clearly articulate what knowledge and skills learners are expected to achieve (DBE, 2011b). Most teachers in the Foundation Phase struggle to translate the curriculum into practice. According to Venkat and Askew (2018), teaching number sense in the early grades is a challenge to many teachers and this is evident in the ANA performance. Teachers’ limited knowledge and understanding of the different methodologies have affected learner performance in early grade mathematics (Mntunjani, Adendorff, & Siyepu, 2018). Tsao and Lin (2012) found that teachers concentrated on learner performance rather than understanding the content of teaching mathematics in the early grades.

According to Bowie, Venkat and Askew (2019), apartheid education in South Africa influenced the quality of teacher development and training. This affected the content and pedagogical knowledge of Black South African teachers. Teachers’ creativity was significantly stifled and they were forced to implement a Eurocentric mathematics curriculum. Ethnomathematics and an indigenous knowledge system were non-existent in the teacher development programmes (Hill, Sim, Spangler, Stahl, Sullivan, & Teyber, 2008). The lack of indigenous knowledge impacted negatively upon the pedagogy teachers could employ in their classes. Aunio, Mononen, Ragpot and Tormanen (2016) state that it is the responsibility of the teachers to adapt their teaching methodologies to suit the learners’ level and address learners’ needs. Hill, Rowan and Ball (2005) agree that the teacher’s content knowledge is significant in improving teaching and learning.

Teacher training and development

Professional teacher development and training is an integral part of quality teaching and learning. However, in the South African context, Venkat and Askew (2012) acknowledge that apartheid has had a negative effect on the process of preparing and developing teachers in South African training institutions. According to the DBE (2011a), the lack of effective professional development can be directly linked to the poor performance of learners. Venkat and Spaull (2015) agree with the international literature on the importance of teacher education for quality mathematics teaching and learning. Professional development is about teachers working together as a team and translating their gained knowledge into practice to grow learner knowledge. Teacher development involves both the mental and emotional participation of teachers (Avalos, 2011). As professionals, Jung (2005) articulates that teachers cannot just be
conveyers of knowledge anymore; they should be in charge of creating the environment prepared for learners to construct their mathematical understanding.

Teacher professional development programmes must include mathematics components of early childhood programmes and should support high-quality mathematics education. An effective professional development programme provides mathematics content, pedagogy, and knowledge of child development (Tsao & Lin, 2012; Ball & Cohen, 1999). Together with professional development, institutional policies for on-going professional development can strengthen teachers’ knowledge and understanding of mathematical content and pedagogy. Through professional development and communities of practice, teachers are communicating, interrelating and learning from each other on mathematics teaching and learning. The constructivist theory emphasises the importance of learners (adult learners – teachers) constructing their knowledge and understanding of mathematics through social interaction and from knowledgeable others.

**Use of resources for teaching number sense**

Neal (2007), in his research, found that young learners learn through exploring, playing and hands-on experience with objects and manipulatives. By playing with objects, learners build graphic images of maths ideas such as numbers, patterns, shape, and size. This experience benefits them to deal with abstract concepts. Clement and Battista (1990) agree that learners will gain a better understanding of mathematics if appropriate resources are used in teaching. The purpose of using learning resources is to assist the teacher with the presentation of mathematical content and to achieve the learning outcomes of the lesson – at the same time helping the learner to acquire knowledge and understanding of the concept taught (Bušljeta, 2013).

To strengthen and develop appropriate number sense, young learners need to have available a variety of hands-on resources that will challenge their thinking and develop their problem-solving skills. Early number sense and the use of counters in the early grades is a necessity. When giving young learners mathematical resources, the teacher needs to plan how to use these in the classroom (DBE, 2011b).

**Theoretical framework**

The theoretical framework that underpinned this paper is constructivism. According to constructivism, knowledge arises through a process of vigorous construction (Mascolo & Fischer, 2005). Constructivism can be traced back to the work of Jean Piaget. When an individual (teacher) encounters a new experience, he/she must merge his/her previous experiences and ideas. This act of merging will result in either changing the initial belief or removing the latest information. When teachers are confronted with new methodologies of teaching number sense, they may either accept the new approaches or continue to teach the way they were taught. As humans create, we construct our knowledge by asking questions, exploring and assessing what we know; either assimilating and accommodating the new information into our cognition or rejecting it altogether (Meyer, Moore, & Viljoen, 2008). In this paper, the researchers focused on the challenge’s teachers experienced in teaching number sense. It also explored calculation strategies teachers used to develop learners’ number
sense in the Foundation Phase. Although Vygotsky's theory concentrates on learners, the theory can be adapted to teachers. Teachers are life-long learners in an educational situation. They are continually adapting and finding new approaches to teaching and learning. In the Foundation Phase, teachers are continually constructing the meaning of the policy documents and other resources to improve their teaching and learning (DBE, 2011b). The constructivist-learning environment encourages thoughtful reflection and experience. In the teaching of number sense, teachers are engaged in the review of their teaching practices and ways to improve their pedagogy. Furthermore, a constructivist environment supports the collaborative construction of knowledge through social negotiation. Teachers need to engage, support and learn from each other in their school context or through communities of practice (DBE, 2011a).

Research design and method

The research adopted a qualitative approach to explore the challenges experienced by teachers teaching number sense in the foundation phase. The qualitative approach was regarded as suitable because it provided descriptive data needed to answer the research questions. Qualitative research assists researchers to understand the social phenomenon from the participants' point of view (Mogashoa, 2014). This approach also attempted to unravel teachers’ experiences and challenges towards teaching number sense. The sampling method was purposive, with specific criteria that all teachers must teach mathematics and have a minimum of five years’ teaching experience. A single case study method with six female teachers (6), two from each Grades 1 to 3 from one township school in the Gauteng North District was chosen. The school did not have the appropriate teaching and learning resources for mathematics, especially maths tool kits and other mathematics apparatus. Five of the participants started their initial teaching careers with the Department of Bantu Education during late 1989 in rural areas. Only one participant started her teaching career in 1998. All these teachers are appointed at a township school in Gauteng North.

Data collection strategies included a semi-structured focus group interview and classroom observation. Focus group interviews were used to elicit information on teachers’ challenges in teaching number sense in the Foundation Phase. It also looked at the calculation strategies teachers use to develop learners’ number sense. The focus group interview responses were analysed to establish the extent to which they could be regarded as a challenge in teaching number sense in the Foundation Phase. Classroom visits for observing how teachers presented mathematics lessons proved a useful way of determining which theories, approaches, methods and teaching techniques were applied. Data were analysed according to the steps outlined by Creswell (2016), namely: (i) reading through all the data; (ii) dividing the text into segments of information; (iii) labelling the information into codes; (iv) reducing the overlap and redundancy of codes and (v) collapsing the codes into themes. Ethical considerations were adhered to by obtaining informed consent from the University of Pretoria’s ethics committee and maintaining anonymity, confidentiality, and privacy when dealing with participants (Maree, 2017).

Findings and discussion

From the data analysis, two major themes emerged that could answer the research questions:
• Challenges experienced by teachers in teaching number sense, and
• Calculation strategies teachers use to develop learners’ number sense.

Verbatim quotes are used as evidence in the results. This section presents findings that emanated from the participants’ responses and classroom observation.

Theme 1: Challenges experienced by teachers in teaching number sense
To address the research question (i), the researcher asked teachers to share their views and experiences about number sense, its importance in the Foundation Phase and their knowledge and understanding of the topic. All six participants agreed that number sense is important in the Foundation Phase.

T1 stated, “The CAPS weighted number sense 65% in Grade 1. This is very good because learners must have a good understanding of numbers, but I have no idea how to work out the time.”

To this comment, T3 added, ”Although more time is given to number sense, my biggest problem is how to teach the content.”

T4 dismally reported, “Our HoD just wants us to teach each section thoroughly; but my problem, I don’t know how to approach some of the sections in the CAPS.”

During the classroom observation and an inspection of teachers’ planning files, the author noted that teachers were not using their CAPS documents as a reference, but instead relying on the DBE workbooks to guide them to teach the content. This indicated to the author a major challenge because teachers were not reading or referring to the CAPS documents. The document provides examples of how to approach the teaching of concepts (DBE, 2011b).

According to the responses from the participants, there was a clear indication that they are experiencing challenges with number sense. They seemed to lack knowledge of methodologies in teaching number sense. In response to this, T5 stated:

“I think I know what number sense is about. It is about teaching the learner by showing how to add, subtract, multiply and divide. CAPS is new to us; when we were trained in the early 1980s, we did not hear of number sense or numbers, operations and relationships. These are all new words and concepts for us. We were trained to teach our learners by showing how to do the calculation.”

When the authors compared the CAPS documents and the syllabus that was used during Bantu Education there is a discrepancy in the terminology. The CAPS document has a wide range of mathematical language, e.g. Numbers Operations and Relationships, which focus on computation skills in comparison to the vocabulary in the Bantu Education syllabus. The syllabus used words such as calculations skills, addition, subtraction, and multiplication. Data-handling was not mentioned in the syllabus; however, the terminology 'graphs' were used and in CAPS this section is called 'Data Handling.' T1 and T3 informed the authors.
“When I trained at the College of Education, we did not hear of number sense and data-handling. Although we had some training with the DBE, I still use the vocabulary that I am familiar with.”

During the observation, the authors noted that teachers were mainly referring to computation terminology such as ‘plus’ and ‘minus.’ When the teacher showed the learners ‘10 + 2’, the word “add” was not used in the class. Although all teachers attended workshops and training of the Revised National Curriculum Statement (RNCS) in 2004 and CAPS in 2012-2013, some teachers were still using the mathematical vocabulary they were familiar with (DBE, 2016).

It was evident from their observations and responses that teachers believe that number sense is about computation (addition, multiplication, subtraction and division). However, according to Van de Walle et al. (2015), number sense is more than computation; it includes a person’s ability to use and understand numbers by knowing their relative values and names. T6 mentioned that teachers need on-going training and development to teach the topic Numbers, Operations and Relationships.

When T6 mentioned training, T1 and T4 shared their opinion on their experiences on training and development,

“You see, the district official, they come once a while and try to train us for one or two hours. They quickly show us how to do addition and subtraction. The last training I went for was on number lines. It was done so quickly that we had no time to ask questions.”

T6 said, “When I ask my HoD for help, she tells me that I went for the training, I should know what to do. I feel very lost when it comes to teaching things like breaking down (decomposition), equal sharing (fractions), number patterns and division in Grade 3.”

T5 mentioned regarding planning for teaching, learning and assessment, “I am not fully trained on how to use the CAPS document, what I do is go to the Rainbow Workbooks and work from the beginning to the end. I was told that the workbooks cover the CAPS, so I do not see the need to read the CAPS and follow it.”

Research by Pittalis, Pitta-Pantazi and Christou (2015) agree that teachers should have a sound understanding of number sense. McLellan (2012) also acknowledges that good knowledge and understanding of number sense is imperative for later mathematical competencies. From the responses, there was evidence that teachers are experiencing challenges with teaching number sense. They need support on how to use different methods and approaches. Venkat and Askew (2018), in their study, found that teachers revealed different levels of understanding of number sense content. According to Education Alliance (2006), there is a lack of content knowledge and understanding among most mathematics teachers and there is a greater need for upgrading teachers’ pedagogical content knowledge of mathematics.

Haylock (2010) affirms that for learners to learn and have a sound understanding of number sense, it requires teachers who understand the curriculum and can explain the content and concepts. Teachers need to have a good understanding of the different components of number sense; it is more than just computation skills. DBE (2011b), states the development of number
sense embraces the meaning of different kinds of numbers, how numbers relate, the relative size of numbers, and representation of numbers in various ways and the effect of operating with numbers. Number sense entails the understanding of how numbers work and how it should be applied in everyday situations.

According to the constructivist theorist viewpoint, people construct their understanding and knowledge of the world through experiencing things (Dennick, 2016), however, due to the lack of training and support teachers are unable to construct their understanding. They are unable to reflect on their teaching approaches to strengthen the teaching of number sense.

**Theme 2: Calculation strategies used to develop learners’ number sense in the Foundation Phase**

Learners do not gain an in-depth understanding of number sense overnight. Their confidence to solve equations mentally requires much practice. Without good practice, learning to mentally compute numbers and how to apply them to various maths questions can become challenging. Number sense starts from kindergarten (early grades) (Dyson, Jordan & Glutting, 2011). At this level, young learners are introduced to the 10 frames to base ten blocks as early strategies to improve number sense. Number sense needs to be cultivated daily (Way, 2011).

The researcher asked the participants to share some of the calculation strategies they use to develop number sense in their learners. Their responses were varied. T1 said,

“*In my Grade 1 class, I make sure that all my learners are doing rote counting from 1-10 every day. When they finish counting, I ask them to point out the numbers on the work cards they have on their tables.*”

T4 stated, “*In my Grade 2 class, I am working with subtractions of tens. I get my learners to count backward from a number. This is done first thing in the morning before they even take out their maths books.*”

T5 and T6 indicated, "*In Grade 3, we do skip counting in 2s, 3s, 4s, and 5s.*"

It was evident that counting is a common strategy that the teachers employ in their classes. According to Humble (2017), counting is a common mental strategy that the teachers employ in their classes. According to Humble (2017), counting is a mental strategy for calculation, building on mental mathematics within number sense. Way (2011) indicates that counting activities contribute towards improving the learning of place value, multiplication and division.

When probed for other strategies teachers use, T5 said,

“*In my class, we use breaking down of numbers when we do addition. It’s so much easier to break down 235 + 123 into [200 30 5] + [100 20 3]; however, when it comes to subtraction, this method is a big challenge to me. I use the method I was taught – subtract from left to right (hundreds, tens, unit method) and it works in my class.*”

The DBE (2011b) depicts the number line, among other strategies, as a method that mediates the teaching of number sense. The use of number lines in teaching and learning offers the opportunity to integrate topics in different ways.
T3 indicated that in their Grade 2 class, “number lines, breaking down, counting back, counting all, 10 frames, skip counting, counting in multiples” are used.

Counting by grouping is a strategy that gets the learners to the next level of counting. According to Anghileri (2001), counting in groups leads to an understanding of multiplication – this was evident in T3’s response above.

T6 added, “I get my Grade 3 learners to manipulate numbers to make multiples of 10 or 100 to make their additions easier. I also impress upon place value of numbers.”

From the views of these participants, there was a fair amount of knowledge and understanding of some of the strategy’s teachers could use in their classes. Teachers indicated that they need the subject advisors to train them on other techniques such as compensation, decomposition, using number games (maths 24, Sudoku) and how to use resources appropriately in mathematics.

T1 said, “The DBE gave us a big box of mathematics teaching resources, they call it the 'Maths Toolkit.' No one came and showed us how to use these items to teach number sense in our class. We need training on how to use resources as a strategy to teach number sense.”

From the interviews, the researcher noted that many teachers’ attitude towards teaching of mathematics was low. Kriek and Grayson (2009) state that teachers’ attitude and knowledge of the subject content determines their practices in teaching and learning. In their research, Bowie et al. (2019) identified gaps in teachers’ content knowledge in mathematics that affected their attitudes. Their findings revealed that teachers need professional development to acquire in-depth content knowledge.

**Recommendations and Conclusions**

This research paper aimed to explore the challenges foundation phase teachers experienced in teaching number sense and what calculation strategies they use to develop learners’ number sense. The verbatim quotes from the teachers and observations highlighted the need for recommendations to support teachers to teach number sense effectively.

To improve the quality of teachers’ knowledge and understanding of number sense, the following recommendations may be useful to address the noted problems. First, teacher development and training for foundation phase teachers must be made a priority so that they can implement CAPS successfully, primarily focusing on the teaching and learning of number sense. Teachers must be made aware of the purpose of teaching number sense and encouraged to start teaching it from early as Grade R. Teachers should not be relying heavily on the workbooks to strengthen learner’s conceptual and procedural understanding of number sense; they should also consult the CAPS documents regularly. Secondly, professional teacher development for in-service teachers should be on-going and not a once-off training. This professional development training session should focus on various strategies (the how of teaching number sense) in the Foundation Phase. Thirdly, teachers must be taught that mathematics is best learned systematically through concrete, semi-concrete and abstract understanding of numbers. Finally, the DBE should consider engaging in partnerships with...
institutions of higher education who can provide in-service teacher training in the teaching of mathematics, especially number sense, which must include content, theories, methods and approaches.

Number sense is crucial in daily life and therefore, an essential aspect of education. Number sense studies have indicated that the development of number sense should be the focus of ongoing teacher development (Aunio, & Niemivirta, 2010). According to Way (2011), it is acknowledged that young learners develop competencies related to numbers and space before their entrance to the school. The intermediate effect of number competence on mathematics achievement suggests that it should be emphasised in kindergarten. Overall, early number sense is critical for setting mathematics trajectories in mathematics throughout primary school years (DBE, 2011a).

Raising the awareness of the importance of number sense in the mathematical development of in-service teachers is key for mathematics education. Foundation Phase teachers should participate in advanced mathematics programmes and courses to understand the importance and significance of number sense. They should also understand how to integrate number sense into mathematics teaching. When teachers understand number sense and know how to teach it, they will help learners develop keen number sense.

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Abstract

Number sense is the ability to think flexibly to use a variety of strategies appropriate for calculating. Engagement with mental mathematics is central to the development of mental models which enable the flexible use of strategies for calculating. Preservice teachers need to develop knowledge of how to support children’s thinking through identifying and understanding the variations in their use of strategies. We focus on five key addition strategies in this paper: splitting, jumping, compensating, non-standard partitioning and re-ordering. We administered the Mental Computational Fluency with Addition assessment to 94 preservice teachers to assess their ability to notice the addition strategies used in calculations, and to ascertain whether there was a difference in their performance per strategy. The results showed that the preservice teachers relied particularly on splitting strategies and that there is need for the critical examination of the mathematics course in which the students are enrolled.

Introduction

“To teach is first to understand” (Shulman, 1987, p.14). These poignant words emerged at a time when Shulman first expressed concern about the knowledge that teachers required to teach. Critical of teacher education institutions who placed emphasis on either developing preservice teachers’ content knowledge or pedagogical knowledge, Shulman proposed that the focus of teacher education should be an amalgam of the two. He termed this pedagogical content knowledge.

Concerns about the education of preservice teachers has been central in discussions on underperformance in mathematics in South Africa. Bowie (2014), in her Report on mathematics courses for Intermediate Phase student teachers at five universities, found that there is significant variance in the time allocated to learning mathematics content, and the nature of the content of the methodology component of the mathematics education courses, across the five programmes. Such research has led to a number of projects initiated by the Department of Higher Education and Training and funded by the European Union. The Strengthening Foundation Phase Teaching and Teacher Education was introduced in 2012, and the ongoing Primary Teacher Education (PrimTEd) project, which is part of the Teaching and Learning Capacity Improvement Programme, was introduced in 2016. One of the main purposes of the PrimTEd project is the development of knowledge and practice standards related to number sense, mathematical thinking and geometry to inform the teaching of mathematics education in primary preservice teacher education programmes.

The four basic operations (addition, subtraction, multiplication and division) constitute a large proportion of the mathematics curriculum in the primary school and was the focus of the number sense group in the PrimTEd project. Number sense is a nebulous and contested concept.
comprised of three distinct constructs, that is, approximate number sense, early number sense and mature number sense (Whitacre, Henning & Atabaş, 2020). Howden (1989) describes it in relation to the explanation of number sense of primary school children (early and mature number sense) as an intuitive feel for numbers. Greeno (1991) offers a more precise conception of number sense suggesting that number sense includes flexible numerical computation and estimation, quantitative judgement and inference. McIntosch, Reys and Reys (1992) extend this explanation suggesting that “number sense refers to a person’s general understanding of number and operations along with the ability and inclination to use this understanding in flexible ways to make mathematical judgements and to develop useful strategies for handling numbers and operations” (p.3). It includes “knowledge and facility with numbers”, “knowledge and facility with operations” and “applying knowledge of and facility with numbers and operations to computational settings” (McIntosch et al., 1992, p.4). The ability to invent, apply and determine the efficiency of calculation strategies provide, in part, evidence of the latter competence.

Of significance to this paper is the view that number sense is the ability to think flexibly and to develop a variety of strategies appropriate for calculating. The development of mental models through engagement with mental mathematics is central to the use of flexible strategies for calculating (Graven, Venkat, Westaway & Tshesane, 2013). The use of flexible strategies enhances children’s number sense, and at the same time, children’s number sense boosts the development of mental calculation strategies.

This paper examines two questions:

- How do Foundation Phase preservice teachers perform in a task that requires noticing of addition calculation strategies?
- Which addition calculation strategies are Foundation Phase preservice teachers most successful at noticing?

**Conceptual Framework**

Mental mathematics is not only important to the development of mathematics proficiency and number sense, but is essential to everyday life. Calculating mentally enables people to draw on a range of strategies from which they select those that they deem most efficient for a particular situation (Pourdavood, McCarthy & McCafferty, 2020). This is unlike situations, mostly written, where children are often required to use standard algorithms. Standard algorithms typically require knowledge of basic facts and procedures, while mental calculations are more complex as they focus on the structure of number and operations and their relationships as well as on basic facts (Rathgeb-Schnierer & Green, 2019). This requires, and simultaneously develops, flexible and efficient mathematical thinking.

What sets mental and written forms of mathematics apart is that mental mathematics involves calculating with the numbers (e.g. 24+25=25+25–1) rather than digits (e.g. 24+25, 4+5=9 and 2+2=4). It also encourages the use of strategies based on the particular sum (e.g. using a near double strategy to solve 21+22, but a friendly number strategy to solve 21+26). That being said, mental calculations do not exclude the use of written notations. As Linsen, Verschaffel, Reynvoet and De Smedt (2015) note, the focus is not about children calculating in their heads,
but rather with their heads. Working with the head requires using and inventing strategies based on the number system and number operations (Verschaffel, Greer & De Corte, 2007). In so doing, children develop a deeper understanding of number, number operations and the structure of number as well as independent, creative and critical thinking, and problem-solving (Rathgeb-Schnierer & Green, 2019). The generation of one’s own strategies both requires and promotes higher-order thinking.

The terminology used for mental calculation strategies differs across the literature. Despite this, there is relative consistency in terms of the types of strategies that children use when calculating. The Curriculum Assessment Policy Statement for Foundation Phase Mathematics (SA.DBE, 2011) suggests that children should be able to use a variety of strategies for solving mental and written calculations in context and context-free calculations. These include counting on or back, using the number line, doubling and halving, breaking down and building up, rounding off in tens, and using the relationship between addition and subtraction. The range of strategies from international literature (and curricula) is far more extensive. Common strategies across the literature include standard partitioning, jump, split-jump, compensation, non-standard partitioning, re-organising, and using the relationship between addition and subtraction. Table 1 provides a synopsis of the different calculation strategies collated by Threlfall (2002, 2009) and Csíkos (2016) and our extension thereof.

Standard partitioning (otherwise known as combining, splitting, breaking down and building up, separation, and 1010) involves the splitting of the addends according to their place value, e.g. 23+14=(20+10)+(3+4)=30+7=37. Jumping or sequencing, count-based, aggregation, N10, breaking down and building up, and standard partitioning refer to strategies where one of the addends is split, e.g. 23+14=(23+10)+4=33+4=37. The split-jump strategy, or 10s, combines split and jump. In this strategy the addends are split according to their place value. Typically, in two-digit addition calculations, the tens are added together first and the units are added to the sum one-by-one, e.g. 23+14=(20+10)+3+4=30+3= 33+4+34.

Hopkins, Russo and Downton (2019) and the CAPS subsume jump strategies into standard partitioning and breaking down and building up, respectively. In other words, they do not distinguish between strategies that split both addends into their place value or split one of the addends into its place value. The CAPS also subsumes non-standard partitioning strategies, defined below, in their breaking down and building up strategy.

Compensation or rounding off in 10s, N10c, and flexible counting all simplify the sum by adjusting one of the numbers to a number that is easier to calculate with, i.e. a ‘friendly number’ (Parrish, 2010). Usually, a number that has 9 or 1 as a unit is rounded up or down respectively to make the calculation easier, e.g. 23+19=(23+20)–1=43–1=42.

The use of a non-standard partitioning strategy, also known as mixed aggregation or compensation, doubling and halving, and bridging through ten, assists in simplifying the calculation by splitting one of the addends, but in a form other than that of place value, e.g. 5+27= (2+3)+27=2+(3+27)=2+30=32. In this example, the 5 is split into 2 and 3 and the 3 is added to the 27 to make 30 (a friendly number).

Noticing, or re-ordering, refers to the process of identifying that it is possible to make a number
that has 0 as the unit, by changing the order of the numbers in the sum, e.g. 25+4+15=(25+15)+4 =40+4=44. The final strategy involves the use of the relationship between addition and subtraction, e.g. 3+15=48; 48−3=45 to create a calculation that is simpler to solve. In this example, subtraction is used to solve an addition sum.

Table 1: Addition strategies typology (adaptation and extension of Threlfall, 2002 & Csikos, 2016)

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<tbody>
<tr>
<td>26+32</td>
<td>26+32 =26+6+30 =32</td>
<td>26+32 =26+6+30 =32</td>
<td>26+32 =26+6+30 =32</td>
<td>35+19 =35+19+1 =40</td>
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<td>(20+6)+30</td>
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<td>(20+6)+30 =30+6 =50</td>
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<td>(35+19+1)−1 =36−1 =35</td>
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<td>=50+8</td>
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<tr>
<td>28+7</td>
<td>28+7 =28+2+5</td>
<td>24+7+6 =24+6+7</td>
<td>25+26 =25+25+1 =25+1</td>
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<tr>
<td>(28+2)+5</td>
<td>(24+6)+7</td>
<td>(24+6)+6</td>
<td>(24+6)+6</td>
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<tr>
<td>=33+12</td>
<td>=29+1</td>
<td>=29+1</td>
<td>=29+1</td>
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<tr>
<td>=50+2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>104−99</td>
<td>104−99</td>
<td>104−99</td>
<td>104−99</td>
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</table>

The four key strategies that form the basis of this paper are splitting, jumping, compensating, non-standard partitioning and re-ordering. We have chosen these strategies as they form the basis of the Mental Computational Fluency with Addition (MCF-A) assessment (Hopkins et
al., 2019) that we utilised with the Bachelor of Education (Foundation Phase) and Postgraduate Certificate in Education (Foundation Phase) preservice teachers in this research.

It is worth noting that strategies, as indicated in the typology used in this research, are ideal-types (Threlfall, 2002). Children’s strategies are often various, individual and nuanced. We believe that the development of knowledge of these different ideal-types is important in preservice teacher education as it is useful for knowing how to support children’s thinking, and in identifying and understanding the variations in their use of these strategies.

**Theoretical Framework**

Kaiser et al. (2017) write that teachers’ professional competencies can be viewed as consisting of cognitive aspects, which include professional knowledge, and affective-motivational aspects, which include their professional beliefs. Similarly, there are two broad approaches to research on teachers’ professional knowledge: cognitive and situated (Kaiser et al., 2017).

The cognitive perspective foregrounds the teachers’ subject-specific knowledge and views teacher knowledge as consisting of separable components (Stahnke, Schueler & Roesken-Winter, 2016). This perspective aligns with the theoretical framework proposed by Shulman (1986) who writes of the distinction between discipline knowledge and pedagogical knowledge and argues for the integration of these in his concept of pedagogical content knowledge (PCK).

Ball, Thames and Phelps (2008) drew on the work of Shulman to develop the Mathematics Knowledge for Teaching (MKfT) framework as a means to specify the knowledge that primary school teachers require to teach mathematics. These frameworks that “emphasise the significance of the teachers’ profound subject-specific knowledge base for the quality of instruction” (Stahnke et al., 2016, p.1) all pursue a cognitive approach to the study of teachers’ professional knowledge. This is the approach that we take in this paper.

Ball et al. (2008) distinguish between two broad knowledge categories: subject matter knowledge and PCK. Our focus is on the category of PCK. PCK is comprised of three domains: knowledge of content and students (KCS), knowledge of content and teaching (KCT), and knowledge of content and curriculum (KCC). While there is significant overlap between these domains (Chikiwa, Westaway & Graven, 2019), we separate them out to focus our attention specifically on KCS. We place particular emphasis on the KCS aspect of PCK in this paper.

KCS, or knowledge of children’s mathematical thinking (Hill, Ball & Shilling, 2008), is based on Shulman’s concept of PCK. In Shulman’s words (1986), it refers to “an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons” (p.9). For Hill et al. (2008), teachers with KCS know the ways in which children think, their conceptions and misconceptions of mathematics topics, the difficulties they may have and the strategies they use when calculating. A teacher would know that when calculating 12+13, a child may use a split strategy (e.g. 10+2+10+3) or a jump strategy (e.g. 13+10+2) or a doubling strategy (e.g. 12+12+1).

**Noticing**

The concept of noticing refers most broadly to the process of “attending to and making sense
of particular events in the classroom” (Stahnke et al., 2016, p.4), and is the theoretical framework adopted in this study. We conceptualise this to be an application of the KCS proposed by Ball et al. (2008) and Hill et al. (2008) and apply the framework of Jacobs, Lamb and Philipp (2010) which focuses on a specific type of noticing: professional noticing of children’s mathematical thinking. Jacobs et al. (2010) separate this into three skills: “attending to children’s strategies, interpreting children’s understandings, and deciding how to respond on the basis of children’s understandings” (p.172).

The first two of these skills in Jacobs et al.’s (2010) framework are the focus in this study. We are interested in the extent to which preservice teachers are able to notice the “mathematical details in children’s strategies and…the extent to which [their] reasoning is consistent with…the details of the specific child’s strategies” (p. 172).

In this paper, the MCF-A assessment is used to surface preservice teachers’ competence in noticing the strategies children use to do addition calculations.

**Methodology**

Ninety-four preservice teachers from a university in Eastern Cape, South Africa, were given the MCF-A assessment task. The MCF-A was developed by Hopkins, Russo and Downton (2019) to assess Grade 3 and 4 children’s understanding of addition strategies. The sample of preservice teachers consisted of 12 Postgraduate Certificate in Education Foundation Phase (PGCE) students, 42 Bachelor of Education Foundation Phase Year 1 (B.Ed1) students, and 40 B.Ed3 students. The PGCE and B.Ed3 students had both had a teaching practice experience in schools for five and seven weeks, respectively.

The assessment was not compulsory. Those students who chose to write the test did so during one of their lectures in the second semester. The students had 20 minutes to complete the assessment. This was extended to 30 minutes, as very few managed to complete it within the 20 minutes. Ethical approval was granted by the university (ethical clearance number 17080801).

The context provided in the assessment was of a young girl who used different addition calculation strategies. The first author read the instruction to the students: *Nqobile is good at adding numbers. She uses different strategies to make adding easier. Your job is to try and think like Nqobile. Explain how she arrived at the number in the box. Nqobile says that 3+4 is the same as 6+1. What numbers did she add to get six?* The preservice teachers were required to explain the strategy used for each calculation. The full list of calculations is provided in Table 2.

Before the students started the assessment, the first author did a few examples with the class. These included 3+4=6+1, 16+99=100+15, 49+50=100–1, and 63+25=80+8. The B.Ed1 group wrote the assessment first, and they did not understand the first compensation example (49+50=100–1), and so a second compensation example was provided. For the sake of consistency, the same examples were used with the B.Ed3 and PGCE groups. There was no discussion related to the terminology of the calculation strategies.
Table 2: MCF-A paper assessment

<table>
<thead>
<tr>
<th>Strategy</th>
<th>No.</th>
<th>Calculation</th>
<th>order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-Ordering</td>
<td>1</td>
<td>$5 + 8 + 5 = \underline{10} + 8$</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$8 + 3 + 2 = \underline{10} + 3$</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$6 + 18 + 34 = \underline{40} + 18$</td>
<td>h</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>$67 + 45 + 43 = \underline{110} + 45$</td>
<td>l</td>
</tr>
<tr>
<td>Compensation</td>
<td>5</td>
<td>$8 + 19 = \underline{28} - 1$</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>$44 + 49 = \underline{94} - 1$</td>
<td>j</td>
</tr>
<tr>
<td>Non-Standard Partitioning</td>
<td>7</td>
<td>$4 + 7 = \underline{10} + 1$</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>$4 + 28 = \underline{30} + 2$</td>
<td>e</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>$36 + 37 = \underline{72} + 1$</td>
<td>i</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>$235 + 238 = \underline{470} + 3$</td>
<td>n</td>
</tr>
<tr>
<td>Standard Partitioning: Jump</td>
<td>11</td>
<td>$28 + 13 = \underline{38} + 3$</td>
<td>f</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>$76 + 21 = \underline{96} + 1$</td>
<td>k</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>$955 + 445 = \underline{1000} + 400$</td>
<td>p</td>
</tr>
<tr>
<td>Standard Partitioning: Split</td>
<td>14</td>
<td>$21 + 26 = \underline{40} + 7$</td>
<td>g</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>$45 + 67 + 82 = \underline{180} + 14$</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>$456 + 356 = \underline{800} + 12$</td>
<td>o</td>
</tr>
</tbody>
</table>

(drawn from the MCF-A assessment of Hopkins et al., 2019)

The order of appearance of the items is given by the letters to the right. For analysis, the items were arranged according to the strategy in focus and then according to the order of appearance. This grouping for analysis is shown in Table 2. This resulted in items being arranged with an increasing number range in calculations.

We coded every student response individually using the categories, split, jump, non-standard partitioning, compensation, and re-ordering. We discussed each instance where the student strategy was unclear to arrive at agreement in the coding of those response.

We coded the data using numerical values if an attempt was made to identify the strategy. If there was no attempt, we coded the sum ‘D’ for ‘did not attempt’. A response was coded ‘2’ if the identified the strategy was correct (e.g. with $28+13=\underline{38}+3$ the student recognised that Nqobile added 10 to the 28 to make 38; or for $8+19=\underline{28}–1$ the student recognised that Nqobile added 20 to the 8 to make 20 and then subtracted 1 to compensate). An example is provided below.

Figure 1: Accurate response to compensation item $19+8=\underline{28}–1$

A response was coded ‘1’ if the student used a different strategy to the one intended. For example, the student used a split strategy for $28+13$ by breaking up both numbers and adding the 20, 10 and 8 together, rather than the more efficient jump strategy; or using a split strategy for the non-standard partitioning expected for $235+238=\underline{470}+3$. Figure 2 provides an example.
A response was coded ‘0’ if the student tried to identify how Nqobile got the number in the box but was unsuccessful. An example is provided in Figure 3.

Figure 3: Inaccurate response to non-standard partitioning item 36+37=72+1

Three student scripts were excluded as the work showed evidence of a response set in their answers. In these cases, the same method was applied for every item, indicating that the student possibly did not give proper consideration to the item, or that they did not know how to respond. Given that the items varied with regard to the strategy in focus, this resulted in some items being coded as ‘2–correct’ despite there being evidence that the student did not know how to distinguish when the strategy should be used and when not. The figure below shows excerpts from two of these scripts. The student whose work is shown on the left included the note: “if a number is on the right side and is positive when it goes to the left side it has to be negative”. This reasoning would account for all of the responses of both students and is indicative of neither student considering the items as varying. We decided to exclude these from the scripts of students who considered each item individually.

Figure 4: Excerpt from two excluded scripts

An excerpt from the third excluded script is provided below. In this case the student attended only to the numbers in the boxes and split them in various ways without considering the left-hand side of each calculation. This set was taken as an indication that the student did not consider each calculation individually and it was therefore excluded.

Data Analysis

The coded responses were captured in a spreadsheet. Items were grouped according to strategy,
and within these strategies were ordered according to their order of appearance in the assessment (see Table 2). This ordering also reflected the increase in the number range used in the calculations.

A total score out of 16 was calculated for each student. One mark was given per fully correct response to calculate this score. In order to analyse each item, the number of responses of each code type was counted. Each item had a count according to the number of responses coded ‘2’, ‘1’, ‘0’ and ‘D’. In addition, the strategy used by a student when their response was coded ‘1’ was also captured.

For each item, a further value was calculated, that of the proportion of responses per code. In order to calculate this, the number of responses coded ‘D’ was subtracted from the total number of students (91) to give the number of attempts per item. Of these attempts, the proportion of codes 2, 1, and 0 were then calculated.

Findings: Overall performance

An overall score was calculated according to the number of items where students identified the correct strategy used to calculate the given number. The mean score for the whole group was 10 (62.5%), and scores ranged from 0 to 16 (100%). The modal score was 13 (81.625%) and the median score was 11 (68.75%). There was no normal distribution, however a polynomial trendline, as shown in Figure 1 reveals an overall left-skewed distribution. The mean score for the PGCE group (n=12) was 8.1 (50.625%), for the B.Ed1 group was 11 (68.75%) and for the B.Ed3 group was 10 (62.5%).

![Distribution of Scores](Figure 6: Distribution of scores (n=91))

The performance of the group varied greatly, as the graph above shows. This variance becomes clearer when viewing the polynomial trendlines for the distribution of scores for each group (see Figure 7). The B.Ed3 score distribution closely resembles the distribution for the full group, but the curve for the PGCE group differs markedly.
Performance analysed per strategy

In order to analyse the students’ performance per strategy type, the items were grouped into the targeted strategies. Those responses coded as ‘did not attempt’ were removed and the proportion of each response type was calculated. The figure below shows the proportion of responses provided that were correct, per item. Items are grouped according to the targeted strategy in the item. As the assessment progressed, the number range used in the calculation increased. For example, items 1, 5, 7, 11 and 14 were all calculations with numbers lower than 50, while items 4, 10, 13 and 16 extended to numbers over 100.

One notable pattern within the data is the decline in the proportion of accurate responses as the numbers used in the calculation extended into larger numbers. This pattern is evident for all strategies, although Item 3 does not conform to this pattern.

Figure 9 shows the average proportions per strategy in order to compare the students’ relative success in working with each strategy. The first graph groups both jump and split strategies as standard partitioning strategies. These are separated into jump and split strategies in the second graph.
Figure 9: Proportion of correct responses per strategy

Standard partitioning and re-ordering are the items that students were most successful in identifying. When standard partitioning is separated into jump and split strategies and compared there is a clear dominance of the split strategy.

The table below shows the proportions of response types per item. Item 3, as well as Items 12 and 13, all have notably higher proportions of responses coded as ‘1’ when compared to other items. These were responses that showed an accurate alternative to the strategy. All responses coded 1 were also coded according to what strategy the student drew on to account for the number in the block.

Table 3: Proportions of responses per code

<table>
<thead>
<tr>
<th>Item</th>
<th>Re-Ordering</th>
<th>Comp</th>
<th>Non-Standard Part</th>
<th>Jump</th>
<th>Split</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.9</td>
<td>0.87</td>
<td>0.63</td>
<td>0.73</td>
<td>0.64</td>
</tr>
<tr>
<td>1</td>
<td>0.03</td>
<td>0.02</td>
<td>0.25</td>
<td>0.08</td>
<td>0.01</td>
</tr>
<tr>
<td>0</td>
<td>0.07</td>
<td>0.11</td>
<td>0.12</td>
<td>0.19</td>
<td>0.35</td>
</tr>
</tbody>
</table>

There were 92 responses that were coded as partially correct. Of these responses, 77 used a split strategy and 14 used a non-standard partitioning strategy. Items 3 and 13 had particularly high proportions of responses that were coded as partially correct compared to other items. In the case of these two items, all such responses involved the use of a split strategy. Examples are shown in the figures below. In the case of Item 12, 11 of the 12 responses coded as partially correct involved the use of a split strategy.

Figure 10: Splitting response to Item 3

Figure 11: Splitting response to Item 13

In the first example, the student has split the two addends according to their place value. They
have then proceeded to add the tens and units to 900 in order to arrive at the 1000 shown in the item. This is as opposed to the more efficient jump strategy in which 45 is added to 955 to get 1000. In the second example the student has split the addends into tens and units and added the tens to arrive at the 40 shown in the item. The more efficient strategy would be to use re-ordering and first add 6 and 34 to calculate the 40 shown. Figure 12 shows another jump strategy calculation that has been solved through a splitting strategy. The more efficient strategy would be to split 21 into 20+1 and to add 20 to 76 to get 96. Instead, the student has shown both addends split into tens and units to demonstrate how 96 is obtained.

The figure below shows a student’s working on items requiring non-standard partitioning, compensation and jump strategy. The majority of this student’s script showed this splitting strategy, and this was also evident on a number of other scripts. Students’ working also frequently showed evidence of an attempt to use splitting as a strategy when incorrect (coded as 0).

![Figure 13: Example of persistent use of splitting strategy](image)

There were marked differences in the way the different groups performed. This was reflected in the trendlines shown in Figure 7, and is also evident in the proportion of correct responses when grouped by strategy and student group. This is shown in Figure 14. It is also interesting to note that several of the B.Ed3 students had used the terminology related to the calculation typologies in describing the work in the examples.

![Figure 14: Proportion of correct responses per strategy and group](image)

The sample sizes do not allow for generalisation, but the clear patterns that emerge, particularly with regard to the dominance of the splitting strategy, are important to consider when reflecting
Discussion

The mean attainment across the three cohorts, that is, the PGCE, B.Ed1, and B.Ed3 groups, was 50.625%, 68.75%, and 62.5%, respectively. Noticeably, the B.Ed1 group performed better than the PGCE and B.Ed3 group. While we expected the PGCE and B.Ed3 students to fare far better than the B.Ed1 students, this was not the case. It is difficult to make any definitive claim as to why the B.Ed3 and PGCE groups did not perform as well. Both groups had extensive teaching practice experiences in schools before participating in the assessment.

We assume that the prevalence of the breaking down and building up strategy in CAPS, and in schools, has influenced the preservice teachers’ use of the splitting strategy in explaining Nqobile’s thinking. As noted in Figure 9, standard partitioning was the most common strategy used. The disaggregation of the standard partitioning items into split and jump confirmed the dominance of splitting as a strategy. It is the two groups who had already had their teaching practice experience, who used the splitting strategy more than all other strategies (see Figure 14). In the CAPS, breaking down and building up includes split, non-standard partitioning and jump strategies. Despite the breaking down and building up strategy being broader than just splitting, the split strategy is actively taught in Foundation Phase classrooms. Westaway and Graven (2018) argue that breaking down and building up according to place value (split) seems to have become the ‘new’ standard algorithm in primary schools.

The preservice teachers appeared to find the items showing compensation strategies to be the most difficult, with under 60% answered correctly. It could be that compensation is used less in Foundation Phase classrooms and in teacher education. As teacher educators, we need to look quite carefully at the strategies that are being privileged in our courses and ensure that the preservice teachers are familiar with a range of ideal-type strategies to support learners’ mathematical thinking.

The B.Ed3 students were the only group who named the different types of strategies in the assessment. They were familiar with the terms breaking down and building up (split and jump), friendly numbers, compensation, and near doubles (non-standard partitioning). We would expect that the B.Ed3 students would be able to name the different strategies. The students used the CAPS terminology in their assessment, which meant that breaking down and building up applied not only to splitting. We suggest that teacher educators should draw on the terminology used in the research literature so that the preservice teachers learn to recognise the more subtle distinctions between types of strategies. Furthermore, we suggest that teacher educators spend more time ‘unpacking’ children’s strategies with preservice teachers using examples of children’s work.

The research provided us with an opportunity to test the MCF–A assessment instrument with preservice teachers interested in teaching Foundation Phase. There are several items in the assessment that we would change. The data was skewed in favour of re-ordering with close to 80% answering these items successfully. The first two items were elementary, only requiring knowledge of basic facts. The third re-ordering question was possibly not a useful item for generating the re-ordering strategy as 25% of the preservice teachers who answered this item
used a split strategy. The MCF-A assessment has motivated us to develop an assessment that examines the extent to which preservice teachers notice ideal-type calculation strategies across all four number operations.

**Conclusion**

The development of children’s number sense is regarded as central to learning mathematics in the primary school. Children with number sense are able to use a wide range of mental calculation strategies in ways that consider the nature of the task (Csíkos, 2016) and setting (McIntosch et al., 1992). They are able to ‘invent’, identify and use efficient strategies for calculating mentally.

This research offers insights into preservice teachers’ performance on a task that requires them to notice children’s different mental calculation strategies. This knowledge is instrumental for the development of children’s number sense. Preservice teachers should be familiar with ideal-type strategies so they can identify and consider learners’ mental calculation strategies to interpret learners' mathematical thinking and understanding (Ball et al., 2008; Hill et al., 2008; Jacobs et al., 2010). Knowledge of the ideal-types should enable preservice teachers to ‘think-on-their feet’ to identify learner errors and know how to address them. The use of the MCF-A assessment has prompted us to look critically at our mathematics education course with the view to enhancing preservice teachers’ competence in developing children’s number sense.

Focusing on children’s mental calculation strategies in teacher education courses should enhance preservice teachers’ competence in attending to the strategy’s children use for calculating, and in interpreting their mathematical thinking and understanding (Jacobs et al., 2010). This suggests that a focus on children’s strategies, and the noticing of their mathematical thinking, has a strong connection to teachers’ knowledge of content and students (Thomas, Jong, Fisher & O'Schack, 2017). Such knowledge, however, on its own is insufficient. Preservice teachers also require knowledge of how to respond to children’s mental calculations strategies and their understanding (Jacobs et al., 2010), thus requiring the co-development of preservice teachers’ knowledge of content and teaching.

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SCIENCE LONG PAPERS
THE COVID-19 PANDEMIC: TIME FOR CRITICAL STEM LITERACY

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Abstract

The COVID-19 pandemic has necessitated communication of STEM information on an unprecedented scale. This paper is a polemic, arguing for Critical STEM Literacy that is personally empowering for knowledge of a health crisis and to critique political policy decisions. Examples are from the United Kingdom discussing ways in which STEM issues have been communicated and interpreted. Of particular relevance are ways data have been translated as different types of graphs and mitigation by social distancing and wearing face masks to limit spread of SARS-CoV-2. Critical discussion of the science providing believable truths and the ways in which complex wicked problems require deeper engagement of the public argue for STEM education that emphasises critical thinking, is socially just, and global.

Keywords: COVID-19, STEM literacy, public understanding, critical literacy

To say the COVID-19 pandemic has affected our lives like nothing before is fast becoming a cliché. One thing is certain; that people in every country have been exposed to unprecedented amounts of scientific, mathematical, statistical and technical information like never before. Overnight we were confronted with concepts in virology, immunology and epidemiology and bombarded by numbers and equations from mathematical modelling and statistics and graphical representations of varying kinds and complexity. As countries grappled with the spread of a disease agent science knew little about, posing a deadly threat to life and health systems and an existential one for economies, political leaders turned to (or abused and ignored) experts, modellers, statisticians and psychologists manipulating STEM information to modify human behaviour in controlling the virus. The relative successes with which the public responded to advice has been key to handling the pandemic. To bring this about requires public trust in often problematic interactions of STEM with politics and the extent to which the public understand the nature of these interactions and STEM concepts that underpin them. Two imperatives emerge: that a degree of STEM literacy is required to negotiate the complex COVID-19 information landscape to enable personal decision taking and that this must be coupled with a degree of criticality so that politicians and experts are called to account.

There are caveats in presenting this paper. The first is that STEM information is bounded by what we currently (in July 2020) know of SARS-CoV-2, its epidemiology and the efficacy of technological and behavioural actions to control its spread. The second is that the paper is framed mainly by the UK context for COVID-19 and ways in which the crisis has been handled (or mishandled), as this is where the author has experienced the pandemic. This paper is a non-empirical, polemic limited to some aspects of STEM relevance: graphical representation of statistical data and the technological and epidemiological evidence behind the wearing of face masks or coverings and social distancing to control viral spread. Before tackling these
examples, in arguing for critical STEM literacy, there are short sections reviewing some of the literature on public understanding and STEM literacy relevant to COVID-19.

**STEM literacy and public understanding**

To support themes of this paper there is a necessary selection of relevant work and ideas mainly in science and mathematics connected with the examples that follow and to establish the concept of critical STEM literacy.

*Science literacy and the Public Understanding of Science*

At the beginning of the last century, Dewey advocated understanding of science for the general public, claiming that, “contemporary civilization rests so largely upon applied science that no one can really understand it who does not grasp something of the scientific methods and results that underlie it...” (Dewey, 1909: 291). As the century advanced, with rapid technological development, the idea of ‘scientific literacy’ emerged to embrace knowledge of basic scientific facts, experimental science and how science might benefit society (Bauer, 2009: 223). Thus, throughout the literature there is a tendency to use the terms literacy and Public Understanding of Science (PUS) interchangeably, sometimes with confusing overlaps.

In the 1970s and 1980s studies of scientific literacy tended to focus on what people might or might not know. For example, Durant, Thomas and Evan’s seminal article in *Nature* (Durant, Evans & Thomas, 1989) revealed that 30% of adults in both Britain and the US failed to realise antibiotics are ineffective against viruses. The dominant research paradigm, as far as the media of the time was concerned, was of deficit. Yet, less publicised aspects of Durant’s research explored public attitudes and interest in science. Of relevance to this paper is the finding that knowledge of medical advances was a priority, on both sides of the Atlantic, yet those who expressed most interest admitted little associated knowledge (Durant, Evans & Thomas, 1989: 11). Later, Miller proposed a ‘functional’ scientific literacy, being sufficient knowledge and understanding to read, engage with and debate issues published in newspapers (Miller, 1998). More recently Fernstein (2011) argued for a science education that helps people solve personally meaningful, everyday problems and make important science-related decisions. Miller refers to a need for educating ‘competent outsiders’ able to access science relevant to their lives rather than ‘competent insiders’, sufficiently educated in science but lacking confidence to question the science they experience in everyday life.

It could be assumed that economic and technological development of a country might go hand in hand with positive attitudes to science and a desire for engagement with it. However, surveys of public attitudes carried out for the Eurobarometer in 30 nations of Europe showed negative correlation between positive attitudes and economic development. It seems the more developed a nation becomes technologically and scientifically, the more sceptical its population is of benefits to society (EUROBAROMETER, cited by Bauer, 2009: 231).

*Mathematical literacy*

Similar for science, ‘mathematical literacy’ has expanded and evolved from the more limited confines of ‘numeracy’, concerned with processes of number manipulation, to embrace a “quantitative literacy” recognising that societies “…keep increasing the use of numbers”
Thus, mathematical literacy has come, like science, to be seen as ‘functional’, using mathematics to take action and decisions that impact everyday life. Consequently, the mathematics curriculum in many countries, including South Africa and the UK, aims to become more contextualised. Yet a drive for contextualisation is not necessarily linked with high performance in mathematical problem solving. As part of the OECD PISA framework for 2012, fifteen-year-olds were asked how often they encountered mathematics applied to real world problems. Correlations of these data with performance on mathematical tasks showed those who frequently encounter applied problems scored about ten PISA score points below students who sometimes encounter such problems (OECD, 2014).

In South Africa, contextualisation of mathematics in social aspects of health is favoured by teachers. A study by Julie (2006) on teachers’ preferences for contextualising mathematics, showed mathematics used to prescribe the amount of medicine a sick person must take and to describe the spread of diseases such as HIV/AIDS ranked highest from a list of possibilities. However, it seems that for some mathematical constructs important for health actions, social contextualisation is less common. Gal (2009) found that in teaching probability, even though the curriculum stresses opportunities to use contexts such as risk behaviour in responding to health issues, most teaching still relies on games of chance for teaching examples.

Of particular relevance for this paper is literature on the interpretation of graphical information prevalent in communicating about COVID-19. Graphical displays contain a multitude of information conveyed by the title, labels and axes and features of the display (e.g., size, spacing, patterns in the data) that vary in complexity. Reviewing research on graphical interpretation, Friel, Curcio and Bright (2001) identify three component processes: (a) to read information directly from a graph, (b) to manipulate information read from a graph and (c) to generalize, predict, or identify trends. Taking this a little further Glazer (2011) proposes that it is also necessary to read between and beyond data to usefully interact with graphs in news reports (Glazer, 2011: 190). A common cognitive error in graph reading is interpreting data iconically, implying ‘reading the graph as a picture’. This occurs when students view graphs as representing literal pictures of situations rather than abstract quantitative information. Other common difficulties at deeper levels include confusing the slope and the height, an interval with a point, conceiving a graph as constructed of discrete points, focussing on x-y trends all of which are added to by the total volume of information conveyed (Glazer, 2011: 185).

Graph comprehension is not just affected by the visual characteristics of graphs outlined above but also by the viewers’ prior knowledge and expertise in associated skills such as graphical, explanatory and reasoning skills (Shah, Friedman & Vikiri, 2005). These authors warn that acceptance of a particular theory or assumed familiarity with data can lead people to see trends in data that are not really there. It seems our entrenched view and the information overload can make us ‘data blind’. This has been a prescient danger of the excessive use of data streams in coronavirus media updates, especially in the UK, as we shall see later.

*Critical STEM literacy*
The term ‘Critical Science Literacy’ (CSL) has been used by Priest (2013) to expand the idea of science literacy and PUS in the modern information age, where the skills to navigate and make sense of information are crucial in selecting which truths to rely on from a list of competing claims. In this paper I expand Priest’s idea to embrace all of STEM. For Priest, CSL requires more than knowledge of just some science background and of methods to collect evidence and validate claims, requiring knowledge of science as social practice. To interact in productive ways that track through the huge amount of information available (particularly for COVID-19) means understanding at least something of how science, and the experts who communicate it, operate in a socio-political domain. Priest points out what knowledgeable practitioners might do when they encounter new claims; examining the source and its credibility in terms of expert pedigree, assessing the extent and quality of peer review, looking at relations and references to key sources and whether political or funding affiliations might lead to bias. This is what Priest sees as engaging with the social practices of science. However, for such a public arena as COVID-19, an extensive evaluation of evidence on which claims are being made from the world of these social practices is largely impossible for the lay public, even for many journalists. Thus, other psycho-sociological methods must be used to judge the veracity of claims. Priest sees CSL keeping an eye out for the exceptions to the general assumption that most honourable scientists are trustworthy and operate in ethical ways.

Until the advent of the internet and the mass access to information it provides, a few journalists with some science knowledge and reporting expertise mediated much STEM information for public consumption. With instant access for anyone to read whatever views they wish, judging veracity of claims has become a more complex and risky business, “Open-mindedness and the idea that truth is subject to revision in the light of evidence are—quite legitimately part of the scientific landscape and recognizing this is also part of critical science literacy” (Priest, 2013:143).

Mathematical (Graphical) literacy and COVID-19

From the beginning of measures in late March to control the spread of COVID-19 in the UK, the public have been subjected to daily televised briefings carried out by a member of government flanked on each side by a scientific and medical adviser. These briefings have shown graphs of data on daily cases of COVID-19 from swab tests, daily deaths from COVID-19 in hospitals (and later in care homes and the community), recovery rates, hospital admissions from COVID-19, occupancy of ICU (Intensive Care Units) beds, numbers of patients on ventilators, international comparisons of death rates, number of swab tests carried out and transport use. These data are communicated through mixtures of bar charts (typically for daily data on deaths and cases) and line graphs (typically for trends or rolling averages in daily data over time and international comparisons). Given the problems that people have in interpreting information from graphs reviewed earlier one might wonder what, if anything, most people make of all this. The situation has not been helped by ways in which data communication via graphs has shifted in type, with sometimes dubious political motives. The graphs shown as Figures 1 and 2 were used on subsequent days early in the pandemic to compare the UK with a selection of other countries significantly affected by COVID-19. Graphs show daily deaths since the outbreaks were first confirmed and hence the lines are of
different lengths on x axes. On 8th April there was a change in graph scale from a logarithmic to a linear one. There appear to be three reasons for this.

**Figure 1. Global death comparisons for selected countries shown at the UK government’s daily COVID-19 briefing on April 7th 2020**

![Global Death Comparison](image)

The first is that the UK and media in other countries talked up the idea of, “flattening the curve,” in controlling the virus and that this trend would be easier to see in the graph in Figure 1, using a logarithmic scale.

**Figure 2. Global death comparisons for selected countries shown at the UK government’s daily COVID-19 briefing on 8th April 2020**

![Global Death Comparison](image)

A second reason is that government data analysts could have been advised that a logarithmic scale is much harder for people to interpret and less likely to make them cognisant of government policy decisions. This is backed up by research by Romano et al. in the US who found that only 40% of people shown COVID-19 data could interpret information from a logarithmic scale compared with 84% given the same information using a linear scale (Romano
et al., 2020). A third possibility is more political, that international comparisons and the overall picture apparent on the linear scale placed the UK in a better light than on a logarithmic version. From early in April death figures coming out of UK hospitals were rising at an alarming rate, but this was nothing compared to the total figures when deaths from COVID-19 in care homes and in the wider community were included. The government decision in March to force hospitals to release beds for COVID-19 patients by sending non-COVID long-term patients into inadequately protected care homes, even without testing them, meant there were soon more deaths in care homes than in hospitals. Eventually the daily briefings were forced to include all deaths on graphs from the 24th April. By early May international comparisons were dropped from briefings and graphical information radically changed to include more pictograms with just a few line graphs of health information from hospitals.

Later in the UK COVID-19 story, information from testing for the virus at local level was urgent to discover if and when any new outbreaks of COVID-19 should be controlled by localised lockdowns. In the city of Leicester (a city with a population of 320K in the East Midlands of England) daily positive results from swab tests available from hospital laboratories seemed to show a downward and stabilising trend for numbers of cases similar to other parts of the UK. But, when results from tests carried out in commercial and university laboratories (Pillar 2 data) were added, an alarming surge in daily cases was evident, opposite to the trend visible for only Pillar 1 data.

NOTE: The graph showing these differences in trends for testing data is under copyright but can be viewed at: https://www.ft.com/content/301c847c-a317-4950-a75b-8e66933d423a

It was only when journalists discovered that Pillar 1 AND Pillar 2 data, while being reported for the whole country, were not being communicated to regional local authorities in time for them to recognise surges in COVID-19, that this alarming gap in data reporting emerged (see Financial Times, 2020).

In this, and the example of international comparisons discussed earlier, there is clearly a case to be made for critical graphical literacy enabling people to challenge and call out inadequacies in and manipulations of data and reporting. The delays seen in recognising trends for Leicester could have cost lives. For educating the public and at school level, these examples could form the basis of useful mathematics lessons and for wider critical discussion of data communication within a political climate that is not always as democratically open as many might assume.

**Mitigation actions for COVID-19 and STEM literacy**

The SARS-CoV-2 virus is particularly virulent and infective, especially as many people with COVID-19 are asymptomatic but remain infectious to others. In most countries suppressing the spread of SARS-CoV-2 has been a priority requiring balance of prevention and mitigation measures by persuasion or legal enforcement. Prevention includes isolation and quarantine of infected or at risk individuals and cancellation of mass crowd events, while mitigation involves strategies such as social distancing or wearing face masks to reduce the chance of infection from one person to another.

**Social distancing**
The idea of people being separated by a distance, somewhere between 1 and 2 metres, is that most respiratory droplets and aerosols transmitted from people containing SARS-CoV-2 or fragments thereof are thought to drop out under gravity (more so for droplets) or are less prevalent at a distance (SAGE, 2020; WHO, 2020). The WHO recommended distance is one metre though many countries have stablished their own rules. For example, India has been maintaining two metres distance as has the UK, Canada and Switzerland while in South Africa, Australia and many others, the distance is 1.5 metres. A briefing paper produced by SAGE (Scientific Advisory Group for Emergencies) concluded, from a meta-analysis of studies on the efficacy of distancing, that it is not possible to say with certainty what a safe distance of separation is, but that best current evidence suggests separation of 1m carries between two and ten times the risk of infection compared with a two metre separation (SAGE, 2020: 21).

A critical examination of the simple idea that social distancing keeps you safe from infection is not difficult. Vagaries of environmental conditions, air movements from ventilation and air conditioning systems and human factors such as the amount of coughing and other methods of violently expressing respiratory particles in droplets or aerosols are all factors affecting spread of the virus (SAGE, 2020) that question distance rules. For example, the Skagit Chorale outbreak in the US state of Washington resulted in 33 confirmed and 20 probable cases of COVID-19 among 61 people from one infector in a 2.5 hour period. Transmission is said to have included aerosol spread exacerbated through singing (Hamner et al., 2020). Findings such as this have led the UK government to be reluctant to open theatres and other venues where enhanced exhalation might feature, though the reasoning behind such decisions, as for so many COVID-19 related policy actions, is hardly ever discussed.

**Face masks**

In early April, when there was acute rise in COVID-19 cases in the UK, wearing masks was seen as weak mitigation in the light of conflicting or inconclusive evidence emerging from reviews of research. The claim was being made that evidence for efficacy of mask wearing came from limited studies of non-SARS-CoV-2 viral outbreaks or from studies that were not RCTs (Randomly Controlled Trials). The same could have been said, however, for coughing into your elbow, social distancing and quarantine, yet these measures were seen as effective and widely adopted (Royal Society, 2020). The situation was not helped by advice from the WHO, expressing similar caution on the veracity of evidence for wearing face masks.

What seems to have shifted the UK government stance on mask wearing by early July is mounting pressure from virologists, immunologists and epidemiologists that, on balance, wearing masks is most likely to make a second wave of infection less likely. Partly this is due to increasing evidence that aerosols, containing respiratory material less than five microns are carried substantial distances in the atmosphere where they are subsequently inhaled (He *et al*, 2020; Royal Society 2020; SAGE, 2020). As seen in the Skagit Chorale outbreak, both droplet and aerosol transmission is increased by strong respiratory actions. There is also evidence that poor ventilation such as in shops, offices and factories may cause recirculation of viral laden air (He, et al., 2020). An additional factor, discussed by He is that viral spreading by droplets or aerosols depends on the progression of the disease and may be highest the day prior to
symptom onset. This confirms the idea, promoted early in the outbreak, that people who do not know they have COVID-19 are just as likely to be infectious and spread the virus as those who do.

The UK government had already moved to make wearing of masks compulsory in hospitals and on all public transport, but as of 14th July, extended this to all shops, following advice from SAGE, The Royal Society, and because of the changing position of the WHO. A rapid review of evidence on transmission of SARS-CoV-2 for the Royal Society concluded:

“Cloth face coverings are effective in reducing source virus transmission, i.e., outward protection of others, when they are of optimal material and construction (high grade cotton, hybrid and multilayer) and fitted correctly and for source protection of the wearer”
(Royal Society, 2020, pre-print: 1)

Like social distancing and many other aspects of the COVID-19 pandemic, public understanding of the nature and status of STEM research and knowledge contributes to the overall trust which the population can place on decisions affecting their lives and indeed that may even save them. As the Royal Society review goes on to state:

“Socio-behavioural factors are vital to understanding public adherence to wearing face masks and coverings, including public understanding of virus transmission, risk perception, trust, altruism, individual traits, perceived barriers.”
(Royal Society, 2020, pre-print: 1)

How these aspects in the quote above interact in the socio-political milieu for STEM literacy frames the following discussion.

Discussion

The COVID-19 pandemic necessitates a response bringing together knowledge and expertise from disciplines that rarely collaborate. To understand transmission of SARS-CoV-2 virus and control or mitigate its spread requires virologists, immunologists, epidemiologists, medical practitioners and mathematicians to work with physicists, who explore dynamics of air currents in transmissions, engineers who design PPE and repurpose engineering plant to manufacture it, and technologists who design effective but cheap face masks. Add psychologists and sociologists, who model and predict COVID associated mental health and human behaviour trends, with economists, who predict and plan to mediate subsequent damage for economies, and you have a truly transdisciplinary example going beyond mere STEM. Educating for and about COVID-19 is an example of what Sharma (2020) calls ‘phronetic science’, responding to and helping understand ‘wicked problems’. Wicked problems are understood as social policy problems of complexity, uncertainty and contested social values (Rittel and Webber, 1973). By this definition the COVID-19 pandemic is ‘extremely wicked’.
Education systems in many countries are ill-designed to deal with wicked problems in the way they compartmentalise knowledge. In my paper to the SAARMSTE conference in 2020, I argued for a change in approach valuing transdisciplinarity, where society and community needs set agendas for learning rather than requirements of curriculum subjects themselves (Braund, 2020). In achieving this, education, particularly that in STEM, will need to undergo a paradigm shift, from one where knowledge is received, static, and unchallengeable to one where ideas and actions are engaged with in a substantial shift to critical literacy. Thus, I see critical STEM literacy comprising STEM knowledge, skills and understanding necessary to engage with concepts and processes impacting personal health decisions, and engaging with interactions of STEM as part of a wider socio-political milieu.

STEM education has sometimes been reticent to engage with politics and associated fields of philosophy and sociology. The pandemic could be a critical catalyst to change this. In the editorial for a special COVID-19 issue of the Journal for Active Science and Technology Education (JASTE), Alsop and Bencze point out that, “Few can now legitimately refute … that science and politics are deeply entwined, constitutive, and inseparable”. The discourse for critical STEM literacy is thus changing and must embrace the wider social and political climate in which personal health issues sit and is why my discussion moves to the relationships, between science/STEM and politics. A critical STEM literacy should and cannot hide from engaging with politics.

Following “THE” Science

A frequent media soundbite used in the UK government during the COVID-19 crisis has been that the government is, “following the science”. The notion of “THE science” gives an impression of just one (most believable and trusted) interpretation of reality. This is to wholly misrepresent science, which proceeds on a multitude of ideas subjected through empiricism to establish which, if any, have more substance than others. In early UK broadcasts the idea of “herd immunity” was promoted, letting immunity develop in the population and thus avoiding a lockdown damaging the economy. As soon as the government were advised, from mathematical modelling, that over 500,000 deaths could result from the herd immunity plan, they backtracked to impose a lockdown, though the delay in doing this may have cost over 20,000 excess deaths according to one of the government’s own modellers (Buchan, 2020). The government’s response to public criticism of this indecision was predictable, that, “they were only following the science”.

In these cases, it is clear there is a relationship between politicians and STEM and other ‘experts’ that the public should be educated to understand and critique. It has to be realised that experts ‘advise’ and government ‘decides’. Critical STEM literacy, therefore, requires knowledge of the social practices of science to educate a more discerning public able to call into question the policy shifts and ‘blame games’ of politicians.

I have already pointed out how graphical literacy is needed to interpret how international comparisons in mortality rates between countries were being communicated; changing from logarithmic to linear scales, probably to make the comparisons between the UK and other
impacted countries look more favourable. The example of reporting only one set of swab test data in Leicester was a clear example of where incomplete data may have cost lives. At times it seems there has been an almost morbid fascination with mortality figures, but here there are perhaps some important lessons to be learned about how factors in a pandemic are measured. In his recent Science and Education article Reiss (2020: 7) points out that many factors could over or under-estimate total mortality for COVID-19 and he considers whether or not some deaths can or cannot be attributed to the disease itself. Even today, as I write, it seems the UK government will cease reporting daily deaths claiming these are possibly an over-estimate though, like so many government pronouncements, this itself needs some critical scrutiny. Measurement is fundamental in all STEM and critical examination of how it is used in health and other contexts should be included in lessons.

*Trust, risk and mitigation*

An intersection of STEM with politics is sharpest for many people when it comes to following ‘rules’ for mitigation strategies. I have discussed STEM factors that make social distancing and wearing face masks problematic in terms of critical decisions at a personal level. The vagaries of viral transmission from person to person that result from seemingly innocent human actions such as shouting and singing, even talking loudly, are anathema to many people. The idea of wearing face masks seems a personal intrusion in a culture where, unlike in many Asian countries, this has never been a custom. As in so many examples from the COVID-19 pandemic, acceptance of rules is a matter of trust in what is being recommended and why. It will be apparent from what I have described that ‘trust’ is something that has been in short supply in the UK. However, given pronouncements of Donald Trump on such actions as taking hydroxychloroquine, shining UV light into parts of your body or oral application of Lysol disinfectant, perhaps UK citizens do not fare so badly.

Mitigation at the personal level requires assessment of relative risk and here we can draw on research from previous experiences of pandemics to explain how people behave. Reviewing research on reactions to Emerging Infectious Diseases (EIDs) such as HIV, Ebola and H5N1 (bird flu), Joffe comments that EIDs are often seen as non-threatening and low risk because they are either geographically distanced or are seen as only being dangerous to ‘others’ (Joffe, 2011: 452). In the case of COVID-19, rapid global spread of the disease dispels the first of these, but the idea of the virus only impacting others has become a major challenge for STEM advisers and governments alike. We have seen in many countries the tendency for large gatherings of people at demonstrations, celebrations and tourist hotspots and that the age profile is mainly of people under 40, a lower risk age group for infection with COVID-19. The fact that many people, especially in this age group, can be asymptomatic carriers for SARS-CoV-2 but can transmit virus to more vulnerable others seems to be missed. There is a case then for including a moral aspect to critical literacy, something that could form the basis for productive debates and activities in schools, colleges, and youth groups.
Conclusion

In this paper I draw on the UK experience of the COVID-19 pandemic to show how an understanding in STEM, especially how STEM data are communicated, builds a wider case for critical STEM literacy. The UK context has readily provided examples for me to critique. Perhaps STEM educators in countries that have been more effective than the UK has at controlling the pandemic would not find such fruitful ground to compose a paper such as this, but I believe the argument for Critical STEM Literacy holds true wherever you are, it is universal. However, I write from a position of privilege. Although in a vulnerable age group, I am white, financially secure, live in an environment with access to green space, with a supportive family around me and able to use a health system, free at the point of delivery. I do not live in an overcrowded favela or township, where to wash hands in running water is a luxury. I would not have to borrow money to get the treatment I need in Trump’s America or be disrespected as a COVID patient in Bolsanaro’s Brazil. I do not make these comparisons to sensationalise but rather to point out that critical STEM literacy should be globally responsive and based in human rights and social justice.

When I was a teacher, I located my biology teaching in a wider world, promoting global values. I asked my pupils to look at health issues internationally such as to combat malaria, HIV/AIDS, TB, cholera and diphtheria and other diseases which had been largely eradicated or controlled in the West such as smallpox and measles. There is a case, as Reiss points out (Reiss, 2020: 4), to bring the study of diseases and how health crises have been handled into mainstream education.

I close my argument for Critical STEM Literacy emphasising what is implied by ‘critical’ in the term. According to a recent OECD report (OECD, 2019: 20), critical thinking aims to carefully evaluate and judge statements, ideas and theories relative to alternative explanations or solutions so as to reach a competent, independent position – possibly for action. I see critical thinking as a way to open debate and discussion about COVID-19 as an example of wider engagement with what have been called Social Scientific Issues (SSIs). In any turn to a curriculum that is globally responsive, has SSIs at its heart and is based on social justice, there has to be a more focussed sense of critical literacy to develop the habits of mind needed to address the wicked problems of the world that will surely proliferate but that future generations must try to solve.

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PHYSICAL SCIENCES LEARNERS’ AND TEACHERS’ PERCEPTIONS OF LEARNING STYLE-BASED INSTRUCTIONAL STRATEGIES

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Abstract

Physical science at the secondary school level has been a national priority in South Africa due to the growing awareness about its contributions to technological development of the nation. However, the performances of learners over the years have not been encouraging. This study therefore is part of a bigger project which investigated physical science teachers and learners’ perspectives about learning style-based instructional strategies in the teaching of Electricity and Magnetism among grade 11 learners in schools around Mthatha to improve learner performance in the subject. To achieve the intended objective and to answer the research question, a purposive sample of 16 high school physical sciences learners and four physical sciences teachers were selected for the study. A collaborative case study design was adopted for the study. The research instruments included an in-depth semi-structured interview. Qualitative data were analysed using a thematic content analysis process. The study found that learners and teachers have a positive attitude towards learning style-based instructions as it improved learner achievement in Electricity and Magnetism. It is therefore recommended that teachers should use appropriate instructional strategies that would be congruent with the learners’ learning styles for effective teaching and learning to take place in the physical science classrooms.

Keywords: Learning styles, learning style-based instructions, perceptions, physical sciences

Introduction

Physical science at secondary school level has become a national priority in South Africa due to the growing awareness about its contributions to the socio-economic and technological development of the nation. According to Ogegbo, Gaigher and Salagaram (2019), as the economic growth is heightened by inventions entrenched in the scientific and technological knowledge applications; the effective teaching of physical sciences becomes very imperative in order to meet the scientific and technological needs of the nation. Therefore, the development of programmes to improve scientific literacy is currently an essential endeavour in the South African context. However, according to Muzah (2011) most South African high school learners are relishing above-average levels of educational resources, yet, their success in physical sciences continues to drop. This low achievement of learners in physical sciences over many years manifest in the yearly results from the National Senior Certificate examinations (Department of Basic Education, 2016) where less than 40% of learners achieved above 40%, indicating a lack of well-prepared learners entering fields of Science, Technology, Engineering and Mathematics (STEM) at South African tertiary institutions.
In comparison to other nations, findings from Trends in Mathematics and Science Study (TIMSS) reveals that South African learners typically perform below the level expected at the international assessment rankings, as noted by Reddy, Prinsloo, Arends, Visser, Winnaar, Feza, Rogers, Janse, Rensburg, Juan, Mthethwa, Ngema and Maja (2016). According to Schoenfeld (2011), the role of the teacher in the teaching learning process is deemed necessary and essential factor to address learner poor achievement in the subject. Studies by Alsubaie (2016) and Graham and Fennell (2001) posit that teachers play an essential role in the successful implementation of any curriculum. This is because teachers sift the core curriculum through to their learners. It has also been observed by scholars (Ball & Forzani, 2009; Ball, Sleep, Boerst & Bass, 2009) that it is the teachers who make the most important contribution to educational enhancements of their learners.

What is at stake here is the extent to which science teachers’ instructions meet the desired needs of learners learning preferences, as cognitive progressions that contribute to learners’ acquisition of knowledge require that in order for learners to solve problems to produce knowledge, learners need to manipulate ideas and information in their environment. In the learning situation however, every learner has his/her own natural ways of acquiring and processing information. These unique ways are described by Singh, Govil and Rani (2015) as their learning styles.

In literature, numerous learning styles and learning style models exist due to the fact that learning is achieved at different levels. In a similar way, instructional strategies also vary. They include demonstrations, lectures or an emphasis on principles and applications (Felder, 1988). Therefore, how much a learner learns in a classroom is often due to the learners’ inherent ability and prior preparation as well as the extent of harmony with the learners’ learning styles and their teachers’ teaching styles. However, sometimes, mismatches occur and, as a result, some learners may get bored or discouraged and may perform poorly in examinations. As such, Guild (1994) recommends the selection of appropriate instructional strategies that match learners’ learning style to facilitate delivery and effective achievement of instructional objectives.

A convergence of the literature shows that learning styles and teacher instructions affect learners’ academic achievements (Magulod, 2019; Poloski Vokie & Aleksic, 2020; Yeung, Read, Robert & Schmid, 2006) but these reports do not specify how the subject content of the physical sciences curriculum, together with learners’ learning styles, affects physical sciences instructions and consequently learners’ academic achievements. There is also limited literature that documents a learning style model specifically designed for physical sciences instructions. Against this background, the study investigated teachers and learners’ perspectives on learning style-based instructional strategies in physical science classrooms to improve learner performance in the subject. The study therefore responds to the following research question:

“How do teachers and learners perceive the implementation of learning style-based instructional strategies in the physical science classroom?”
Theorising Learning Styles
In 1988, Felder and Silverman developed a learning style model. This model, according to Hawk and Shah (2007), defined learning style “as the characteristics, strengths and preferences in the ways individuals take in and process information” (Felder & Silverman, 1988, p. 674). This model was designed to capture the most important learning style differences amongst engineering students. It was believed that this model would provide a good basis for engineering lecturers to plan a teaching method that would cater for the learning desires of all students (Bosman, 2015). It was also assumed that learners differ in terms of the learning styles and learning strategies that they use.

The Felder-Silverman Learning Style (FSLS) model (1988) categorises the learners’ learning style preferences in a scale of four dimensions. The first dimension is the sensing-intuitive learning style (LS). Sensing learners learn from realities and physical materials. They are mostly problem solvers and solve problems systematically and are likely to be enduring on task. They are precise and practical. However, intuitive learners prefer to learn non-representative material, such as concepts and their causal significances. They are more able to discern prospects and associations and tend to be inventive and ingenious than sensing learners.

The second dimension, the visual-verbal LS, distinguishes between learners who learn particularly from what they see (e.g., pictures, diagrams and flow-charts), and learners who learn from word-based representations, either it is spoken or written. The third dimension differentiates between active and reflective LS. Active learners learn by active participation with the learning material, experimenting with the material and communicating their observations to their peer. They also learn actively in groups where they discuss the learning material. In contrast, reflective learners prefer to deliberate about the learned material and reflect on the content. They also desire to work as individuals or perhaps in a small group together with their friends.

In the fourth dimension, the learners are categorised according to their understanding on the learned material. Sequential learners, therefore, learn in gradual leaps and work systematically to find answers to solutions. In contrast, global learners employ all rounded thought-provoking process and learn in large leaps. They tend to process information randomly without knowing relations but, after they have learned adequate material, they abruptly get the whole picture. Then they can solve complex problems, find associates between different concepts. Because the whole concept is important for global learners, they tend to be concerned in summaries, whereas sequential learners are concerned with specifics.

The Felder and Silverman learning style model was selected as the basic instructional model for the taxonomy of learning and teaching in this study. This is because; the model has been developed for improving engineering education in general and hence can be applied to other fields of science, for example, physical sciences. Furthermore, Felder-Silverman’s learning styles model appears closer to the actual classroom physical science instructional practice. The model has also been successfully implemented in previous works (Carver, Howard & Lane, 1999; Hong & Kinshuk, 2004) and has further been validated by other scholars (Zywno, 2003; Allert, 2005).
Constructivism as a framework for deciding instructions

According to Bada and Olusegun, (2015), “constructivism’s central idea is that human learning is constructed so that learners could comprehend new information upon the basis of prior learning (p.67). This acquisition of new knowledge of learning abruptly differs from the one in which learning is the unreceptive passage of material from one person to another, a view in which responded, not structure, is vital (Bada & Olusegun, 2015; Hoover, 1996). According to Hoover (1996), in constructed knowledge, learners create new understandings using what they already know and previous experiences influence what new knowledge they will construct from new learning experiences. Hoover (1996) further opined that constructivism has two central ideas. The first idea is that learners construct their own knowledge employing their prior experience and that prior experience alters information they will create from their new learning environment. The second idea centres on the fact that knowledge is acquired actively and that learners challenge their thought in light of what they come across in the new learning environment. If what learners come across is inconsistent with their present understanding, their understanding can change to accommodate the new information. Learners continue to be active throughout this process: they apply current understandings, note appropriate features in new learning experiences, judge the consistency of prior and emerging knowledge and, based on that judgment; they can adjust their understanding (Phillips, 1995). Bada and Olusegun (2015) opined that, in the constructivist classroom, the attention inclines to shift solely from the teacher to the learners. The classroom is no longer a place where the teacher transfers information unto unreceptive learners who wait upon the teacher like empty barrels to be filled. The teacher functions more as a facilitator who mentors, trains, mediates, prompts and helps learners develop and evaluate their empathetic and learning in the new environment.

In this study, the constructivist framework guided both the intervention and the methodology as the framework assisted in the design of instructions by checking whether learner involvement in science processes moved them from passive learners to active learners.

Methodology

A qualitative, collaborative research was employed. According to Silverman (2000), a collaborative study is a kind of qualitative research done in collaboration with practitioners with the principal aim of generating knowledge and understanding of practice. Hatch (2002) argues that collaborative qualitative research brings in both participants and researcher perspectives to the analysis of the phenomena under investigation. In this study, the participants’ perspectives were incorporated into the research largely in the form of participation in post-teaching discussions as well as interviews. Under the collaborative research, the case study method was followed. This method allows for the investigation of one or a few cases in order to gain an understanding of one phenomenon in depth within a limited context.

This study was interpretive in nature in that the researcher seeks meanings and relationships between theoretical and contextual conditions. Hence, data was collected at the end of a six weeks period of interaction and observation of the practices of the four science teachers and
their Grade 11 learners, thus providing the researcher with thick data on classroom interaction in their specific contexts. Data collection techniques selected was used to extract data on what teachers did and how they did it (direct classroom observations) as well as why they did it (interviews). Although the findings from case studies cannot be generalised but can provide insights into aspects of the big picture of (in this case) the possible use of learning style-based instructions as a strategy for implementation of the new science curriculum at FET level to improve learner performance in the subject in South Africa.

The 16 learners were purposefully selected based on their consent to participate. The average age of the learners was 17 years (age range 16 to 18 years). In addition, all sampled learners were selected from English medium schools since the two compulsory official South African languages offered to the learners were English or IsiXhosa (as first language) and English, IsiXhosa or Afrikaans (as second additional language). This study purposefully sampled one teacher (ensuring gender balance) each from the four sampled schools. These teachers were selected for the study because they were keen to try out the learning style questionnaire and the learning style-based instructional strategies in their respective classrooms. In addition, these teachers willingly agreed to re-sequence their pacesetter content to teach electricity and magnetism in grade 11 in the first few weeks in term 3 of 2017 during the period of the study. The sampled teachers were trained on how to develop and implement learning style-based instructional strategies in the science classroom. After the workshop, the participant teachers implemented learning style-based instructional strategies in their classrooms for 5 weeks. At the end of the intervention, the participants were interviewed to find out their perceptions and experiences with the adaption of teaching styles to meet learner needs in the science classroom. Open-ended questions were used to give participants freedom of expression of their thoughts.

Data analysis process was followed by thematic content analysis to identify themes for each category. Clarke and Braun (2013) explained that “thematic analysis is a method for identifying, analysing and reporting patterns (themes) within data” (p.79). The transcripts were taken back to the participants for member checking. Original quotes from participants were used to support themes that emerged.

Findings

Participants’ responses were centered on the following perspectives that they might encounter. From these, 6 themes grouped into 3 categories related to learning experiences with the implementation of learning style-based instructions, challenges of implementing learning style-based instructions and reflections on the short intervention were generated.

**Table 1: Perception and experiences with learning style-based instructions**

<table>
<thead>
<tr>
<th>learning experiences with the implementation of learning style-based instructional strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Theme 1: Kind of instructional approach that worked in the classroom.</td>
</tr>
<tr>
<td>• Theme 2: Influence on learner interest, motivation and achievement.</td>
</tr>
</tbody>
</table>
Theme 3: Personal perception of the influence of learning style-based instructions.

**Challenges of implementing learning style based instructions**

- Theme 1: Resources needed to implement learning style based instructions.
- Theme 2: Limitation of resources.

**Reflections on the short intervention**

- Theme 1: Awareness of learning styles and learning style-based instructions.

Source: Author’s own summaries

**Theme 1: Kind of instructional approach that worked in the classroom**

Most of the learners recounted that they enjoyed teachers who elaborated on the science concepts by utilising different instructional strategies, for instance, the use of charts, illustrations, and, gave comprehensive descriptions and good examples that made certain that they understood the concepts taught in the classroom. This was evident in their responses as described by one participant:

*I like science teachers who demonstrations the lesson to explain concepts in front of the class. I found this helped me understand better.*

There were comments made on group work as style-based instructional strategy when studying physical science. Some learners indicated that they liked science teachers who give tasks on work done in class as a group and assigned responsibilities to group members. One learner narrated:

*Learning in groups is very exciting. We shared ideas. Sharing ideas makes me understand and remember what we did in the classroom better. I did not feel bored as I used to do before.*

Mention was also made of active learning. Many learners indicated that they took the initiative to be involved in the lesson and developed a deep understanding of the subject. Comments were also made about teaching styles that facilitated practical activities. Two learners stated:

*I like teachers who take time to let learners experience the teaching/learning process by involving us in practical activities in the classroom or in the laboratory, thereby sharing knowledge as we undertake the activity.*

*Practical activities are fun. It makes us relate science to real life situations. Also during practical activities, we are able to work together with our peers to communicate our findings.*

This indicated that the learners wanted to interact with the teacher when trying to understand problem areas in sciences. The teacher would then be able to help them improve their current performance through the sharing of their knowledge with the learners thus supporting them to develop better insight into sciences.
Theme 2: Influence on learner interest, motivation and achievement
The responses substantiated the inferences that the participants assigned responses based on interest and motivation categorically. Some participants opined that the use of the learning style-based instructional strategies have stimulated their interest in sciences as learning becomes more understandable. Typically, two participants recounted their experiences as follows:

*Learning style-based instruction has impacted on my interest because the teacher uses different methods of teaching which have increased my interest in physical science. I do enjoy learning science all day.*

*When there are diagrams and examples, I understand the teacher’s lesson better and my interest is elevated. In other words, this teaching style has increased my interest and understanding in the way I learn.*

Some of the respondents limited the use of the learning style-based instructional strategies to motivation. This group believed that the use of these strategies in the lesson has inspired them to put in much effort in the subject.

*Learning style-based instructions have motivated me in achieving the highest level which is level 7 instead of level 5 which I used to achieve. Learning style-based instructions gave me that enthusiasm to keep finding questions and come up with solutions on my own. This instructional strategy also made me understand lessons and that has boosted my performance.*

Theme 3: Personal perception of the influence of learning style-based instructions
Most of the learners contended that they now find the subject enjoyable; they are capable of doing more as they see that the subject is interesting and they have been able to improve upon their performance in the subject. Typically, two learners recounted their experiences:

*My performance has improved drastically in the subject and I no longer see physical sciences as a difficult subject but as any other subjects like English. I now recognise that physics is not a challenging subject at all.*

*I am doing well in physical sciences and my personal perception towards the subject has changed. I no longer see the subject to be difficult, but easy and fun when working with others on an activity.*

This finding corroborated with the findings from the teachers’ interviews. Many of the responses recorded focused on creating science lessons that are interesting to help them to learn science. One teacher narrated:

*This teaching strategy implemented enhances learner interest in physical sciences which enhanced their retention in the subject.*
Some teachers believed that learning style-based instructional strategies improve learners’ achievements in the subject. Two participants shared their views as follow:

_Honestly, when I began implementing learning style based instructional strategy in my science classroom; it has encouraged learners to become participants in the lessons. Not one person sleeps in the class and no one complains of the subject being difficult._

_Obviously, the implementation of the learning style-based instructions in my classroom has led to increased performance among my learners, since all the learners in the classroom were catered for during the teaching/learning process. This made them understood the concepts and therefore achieved in the test._

Responses from the teachers indicated that intensifying the utilisation of range of teaching styles is not to be imposed but should be introduced gradually into the classroom. Assisting learners to identify their learning styles and acknowledging their differences will augment their experiences and diversity to their scientific world.

**Challenges of implementing learning style-based instructions**

**Theme 1: Resources needed to implement learning style-based instructions**

The participants expressed concern about the lack of necessary resources and funding. Materials necessary for the successful implementation of learning style-based instructions include: teaching aids, curriculum materials, apparatus, reagents, textual resources, projectors, computers, videos and audio recordings, visual aids, white and black boards and laboratories. The availability and implementation of these resources will yield positive attitudes which will reinforce learner achievement in physical sciences. Some teachers specified that availability of resources, such as, curriculum materials, apparatus and equipments, and also provision of in-service training for staff would inspire them to use a diversity of teaching styles to accommodate learner differences in the classroom. Although teachers possess positive attitudes towards the implementation of a diversity of instructional strategies to meet diverse learning styles, they also require ongoing opportunities to build their understandings and abilities, as argued by NRC (1996). These enduring opportunities include attending professional development workshops, pursuing further studies and engaging in research. Each of such experiences would give teachers the chance to plan properly and work well with colleagues in order to accelerate change.

**Theme 2: Limitation of resources**

The participants perceived that external factors, such as limitation of resources, planning time, staff development and attitude, influenced the teachers’ ability to implement these diverse instructions to cater for different learning styles. A lack of proper preparation constraint was a major concern for some participants. These teachers were of the view that incorporating a variety of instructional strategies is simply adding more work to their workloads. The time required for preparation and delivery was a commonly cited impediment to implementing learning style-based instructions. One participant shared the following sentiment:

_Implementing learning style-based instructions is a challenge for teachers as it takes a_
lot of energy and time to prepare and deliver this type of instructional strategy in the science classroom.

Class size emerged as another factor that impedes the implementation of learning style-based instructional strategy. Many of the participants complained about having large classes consisting of 55-60 learners. One participant narrated:

*It’s so difficult to have about 50 learners in one classroom and planning instructions for each one of them in the classroom.*

Some teachers were also worried about class management as many sensed that learner misbehaviour could hamper the inclusion of a diversity of instructions. However, the teachers thought that many learners articulated behavioural problems owing to dullness or frustration that might result from the nature of instruction that is given. One participant narrated:

*I see some learners getting bored if their learning styles are not catered for in the lesson.*

Another challenge faced by teachers in implementing this kind of learning-teaching style, was their inability to complete the syllabus on time. These teachers thought that the pacesetter is time bound and that this type of learning style takes time and effort to plan and prepare before implementing it in the classroom. One participant narrated:

*Naturally, it is not easy to meet all the learners’ learning needs in a particular lesson, and this posed a challenge in the implementation of learning style-based instructions in the physical science classrooms.*

**Reflections on the short intervention**

**Theme 1: Awareness of learning styles and learning style-based instructions**

The short professional development intervention employed in this study was informed by Warford’s (2011) “zone of proximal teacher development” (p. 253), a feature of Vygotsky’s (1978) social-constructivist view of zones of proximal development, which signifies the distance between what teachers can do on their own and a proximal level they might accomplish through structured, facilitated assistance from more capable others. In hypothesising such support, a three-day workshop was organised for the sampled teachers which was facilitated by the researcher. The participants were interviewed to gain insights from their thoughts on the workshop and to know how this new knowledge might influence their future classroom practices.

Responses from participants showed that, at the beginning of the workshop, two participants out of the four were unaware of the concept of learning styles and learning style-based instructions. Nevertheless, the two participants that were aware of it did not design instructions with learners’ learning styles in mind. After the short professional intervention, there was a shift in teachers understanding of designing instructions with learners learning styles in mind. The following sentiments were expressed by the participants:
I wish we could have more days for this intervention program so that I could learn more on the
design of learning style-based instructions.

I think we should extend this training for a week or so, so that we could learn more about
designing learning style-based instructions.

This finding is corroborated with the findings from Herman, Clough and Olson (2013) that the
level of internalisation of new knowledge and practices increases with the extent of steady
commitment. It can for that reason be anticipated that, as the teachers continue to commit to
the training and evaluate their own practices as they carry on to implement learning style-based
instructions in their various classrooms, they can anticipate higher levels of achievement
among learners in physical sciences.

The results indicate that the teachers responded positively towards the workshop and
establishing remarkable levels of appreciation of learning styles and learning style-based
instructions. This was observed during the group presentations. However, Buma (2018) warns,
such outcomes should be interpreted with care, being careful of the probable contrasts between
the progressive workshop setting and their usual classroom environment.

Discussion

The four teachers appropriately used web-based resources, PowerPoint or other technological
tools and techniques to reflect an awareness of different learning styles. The teachers further
elicited feedback validation of learners understanding of material, interacting with learners
working in small groups during the class, and provided feedback that gave learners direction
for improvement, and an adequate amount of time to respond to questions, that showed
enthusiasm for the subject matter and teaching. Many studies have described aspects of
classroom practices by the teacher which are related to effective classroom learning and learner
outcomes (Brophy, Good & Wittrock, 1986; Wang, Haertel & Walberg, 1993). Close
monitoring, adequate pacing and classroom management as well as clarity of presentation,
well-structured lessons and informative and encouraging feedback have generally been shown
to have a positive impact on learner achievement. This was evident in the classrooms that were
used for the study. This finding corroborated with the literature reviewed which disclosed that
the quality of teaching was considerably enhanced if teachers altered their teaching styles to
cater for the diverse learners in their classrooms as suggested by Kamboj and Singh (2015).
Kamboj and Singh (2015) further indicated that learning style-based instructions create learner-
centred instructions, and make the class to be independent and less teacher-dominant, but
stresses on students’ active participation in the lesson. In this way, learner competence is
improved.

Participants indicated overwhelmingly that learning style-based instructions were exciting,
engaging and gave learners an understanding of the concepts taught. A common factor which
was emphasised through most of the learners’ responses was that they developed a strong liking
for hands-on activities. They emphasised that hands-on activities engaged them in the
teaching/learning process. Many learners indicated that they developed their own ideas from
the teachers’ instructions that required of them to reflect on their work. This finding
corroborated the findings of Packer and Bain (1978) who indicate that it was easier for learners
to appreciate the learning process when teachers’ teaching styles were aligned with learning styles.

A major finding was that learners adored teachers who elaborated on the science concepts by utilising different instructional strategies, specifically, the use of resources such as charts, figures, and illustrations and that detailed explanations and good examples ensured that they understood all the concepts their teachers taught them. Some learners indicated that they liked science teachers who give tasks on work done in class as a group and assigned responsibilities to group members while others mentioned active learning. Many learners indicated that they took the edge to engage in the lesson and developed a profound grasp of the subject. This finding concurred with the findings of the study by Packer and Bain (1978) who pronounced that it was easier for students to appreciate the learning process when teachers’ teaching styles were in alignment with their learning styles to improve student attitudes, teamwork, citizenship, ethical behaviour and performance.

When the results of the qualitative study were further interrogated, it became evident that learners preferred teaching styles that facilitated practical activities. Proponents of the learning styles framework (e.g. Aliweh, 2011; Felder & Silverman, 1988; Tulbure, 2012) believe that congruence between teaching and learning styles is an effective pedagogical approach designed by best practice. Most learners believed that the implementation of the learning style-based instructional approaches stimulated their interest and curiosity in the subject as learning becomes more understandable. This finding is in line with the findings of the study by Alnujaidi (2019) who found that aligning instructions to learning styles give students an opportunity to learn, allow them to become conscious of their strengths and weaknesses, and ultimately influence their learning, assertiveness, conduct and enthusiasm. This finding was further corroborated by the findings of Brown, Terry and Kelsey (2013) who stated that, when students’ learning styles correspond with appropriate teaching styles, their enthusiasm, and achievements are enhanced.

When asked about teacher’s views regarding the challenges of implementing learning style-based instructions in their science classrooms, the teachers expressed concern about the lack of essential teaching resources, preparation time, materials, and funding. One teacher was concerned about learners’ behavioural problems and their attitudes towards the implementation of learning style-based instructions. The challenge of handling large classes with many different learning styles poses a big problem for many science teachers. The teachers perceived that external factors, such as a limitation of resources, planning time, staff development and attitudes, influenced the implementation of diversity of instructional strategies.

**Conclusion**

This finding means that for a diverse group of learners, science teachers should differentiate and diversify their own teaching styles, although, it is neither likely nor desirable to modify instructions to suit individual learning styles of each learner, should teachers diversify teaching methods to accommodate different learning styles during a science lesson. It is therefore recommended that; different forms of instructional materials could be implemented in the science classroom to accommodate learners with different learning styles. Thus, instructional
designers should use different formats of instructional materials in the ways that can benefit
the majority of science learners.

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INVESTIGATING SCIENCE STUDENTS’ WATER LITERACY IN RELATION TO A LOCAL STREAM: A CASE STUDY OF ONE HIGH SCHOOL IN LERIBE, LESOTHO.

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Abstract

Water is a critical part of environment, and its global significance is reflected in the UN SDGs, adopted by member states in 2015 to achieve environmental sustainability. This study investigated grade 10 science students’ water literacy in relation to their local stream using water literacy theory. The aim of the study was to find students’ knowledge of the health of their local stream and the associated biological indicators, and stream-related socio-economic problems and possible solutions to them. The study employed a case study design, 40 grade 10 students participated. Data were analysed qualitatively and quantitatively, to determine themes, patterns and frequencies. The results show that many students had sound water literacy in terms of their ability to identify water-related problems and willingly to take action, but had limited water literacy on safety and quality of water.

Keywords: Water literacy, Science Curriculum, Water quality, awareness

Introduction

The study was conducted to investigate science students’ knowledge about their local stream, with focus on its biological and social aspects. Water is an important resource of all life; it is needed for the survival of all organisms including human, food production and economic development (Khatun, 2017). Water is at the core of sustainable development, energy and food production, healthy ecosystems and for human survival itself (United Nations, 2016). One of the ways to change students’ behaviour towards water is by providing good water education which promotes water literacy. According to Brody (1995), teaching basic science concepts would help in conscious use of existing water resources, water saving and water pollution prevention and most importantly the awareness of the importance of water for all living things. Water-related topics are incorporated in the curricula with multi-interdisciplinary approaches and the most involved are sciences and Geography; however, there is lack of field and extracurricular activities in schools (Amahmid, 2018). Onukogu et al (2018) argue that there is a great deal of responsibility to be assumed by schools to undertake the task of raising responsible, conscious and qualified generations on the water issues. Cabuk & Karacaoglu (2003) re-emphasize that the most effective way for individuals to become responsible for the environment is through education.

One of the main purposes of environmental education in school is to acquaint and sensitize the young minds to the water conservation and appropriate usage, to inculcate in them healthy personal and social attitude and behaviour towards environment (Iyang-Abia & Umoren, 2005). Molapo, Stears & Dempster (2012), add that the current view of education for
sustainable development promotes action-based environmental learning and requires teachers to be active in transforming learners’ attitude and values by involving them in addressing environmental problems in their communities. Lesotho’s intended National Curriculum envisages learners as action-oriented citizens, who are multi-skilled to address vulnerable Lesotho environment and who have the ability to participate in the country’s decisions (NCDC, 2003). In Lesotho, there are indications that stream water is continually being polluted; for instance, Deepa & Kevin (2011) allude to industrial waste water discharges being released untreated into the streams. According to Huxhold (2016), water literacy encompasses knowledge areas such as the quality and cleanliness of water. Water quality, on the other hand, is the suitability of water for drinking, recreational use and as a habitat for aquatic organisms and other life forms (Neary, 2002). The degree to which students are aware of water quality is linked to how they interact with and experience water e.g. drinking water, engaging in outdoor recreation (Barnett et al, 2018). Against this background the present study therefore investigates students’ water literacy, as a first step to promoting sustainability of streams in Lesotho.

It can be argued that some attempts have been made to develop students’ water literacy and environmental awareness in Lesotho. The Lesotho secondary school science curriculum contains relevant content such as Environmental changes, with focus on observation of the environment and associated problems, uses of fertilizers and their effects on the environment and economic importance of water and effects of water pollution to living organisms have been included in the Curriculum and Assessment Policy (MOET, 2008). The Policy (MOET, 2008) further states that learners should also develop knowledge and skills towards sustainable use of environment for individual and societal development. Three science disciplines, Physics, Biology and Chemistry have some topics that can promote students’ awareness on water and develop water friendly attitude in students that will enable them live and interact with their water in a friendly manner (Onukogu et al, 2018).

Research questions

The study was guided by the following research questions:

(a) What is the students’ knowledge of the health of their local stream and the associated biological indicators?
(b) What is the students’ knowledge of the stream-related socio-economic problems and possible solutions to them?

Literature review

Integration of water issues in the curriculum

Peine and Guilboult (2012) state that water across the curriculum helps answer some basic questions and explain some fundamental facts about water supply. They further content that:

Water can be studied in Maths through charts and graphs that show water usage; science through pH; Arts through literature, poetry and writing; Technology through the use of online research and web quests; Social studies and Geography through maps.
and studies of how other cultures use water; and, of course, Arts, music and Theatre through creative activities (2012: pp.:4)

Menn (2018) emphasized that bringing water and sanitation issues into the curriculum provide a means of encouraging young people to understand not only the wider water and sanitation concepts, but also the effects of their own behaviour on water, its quality and eco-system. Additionally, education can help equip next generation with knowledge and attitudes that promote a wise use of water and appropriate hygiene behaviour (Schaap & Van Steenberge, 2001). There is also a view that school curriculum can be reorganised by integrating water and sanitation issues into regular school subjects (Menn, 2018 & Schaap and Van Steenberge, 2001). On the other hand, according to Mohammed et al,

**Majority of studies found out that people, regardless of gender, area, age or education have high information relative to water pollution which might due to constant use and frequent need to water and their perceptions towards water quality challenges like color, odor, flavour etc. (2014: pp.: 2680)**

The researcher’s view point is that the inclusion of water issues in the curriculum remains the best way to solve water-related problems in the streams. This is in line with the United Nations Environment Program (UNEP) (2010) position that the development of water resources curriculum is the most important tool for solving water problems, so students and teachers are the potential persons to enhancing water resources management. (Schaap & Steenberge 2001) note that by introducing water into the curriculum, education can help raise the next generation level of knowledge on the sustainable water, hygiene and sanitation behaviour. According to the present Lesotho JC science syllabus, water can be integrated in topics such as Environment and Environmental Changes, Ecology, Effects of Fertilizers on Land and water bodies; Economic Importance of Water and Effects of Water on Living Organisms. The researcher analysed different secondary science textbooks used by teachers and students at school where the researcher is teaching. The purpose was to find topics containing the word ‘water’ in them.

![Figure 1. Chart of topics containing the term water](image)

**Figure .1. Chart of topics containing word water in each science book.**
According to figure 1 above, Excel in science Form B is the textbook containing most topics with word water in them, 10 topics. It is followed by science for Lesotho Form C with 9 topics containing water in them. While excel in science Form A and Science for Lesotho Form B have equal number of topics (8) containing word water. It is also noted that science for Lesotho Form A has fewest number of topics containing word water, 6 topics.

**Schools, sustainable development goals and water.**

In effort to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030, the UN members adopted 17 Sustainable Development Goals in 2015 as a guiding framework (UNDP, n.d.). Sustainable development was first defined by the World Commission on Development and Environment as development that meets the needs of the present generation without compromising the ability of future generations to meet their own (United Nations, 1987).

Fuertes-Camacho et al (2019) argue that, it is necessary for future teachers to acquire sustainability competencies and competencies in Education for Sustainable Development (ESD) to bring about changes in the society. Sustainable Development Goal (SDG) 6 calls for availability and sustainable management of water and sanitation for all before 2030 (UN conference, 2012). Additionally, Yamazaki et al (2015) note that Education has been one of the core components of the Millennium Development Goals (MDGs), and it is expected to continue to play a critical role in the achievement of the SDGs. Education is a very important tool in addressing human resource capacity and developing ownership for improved water and sanitation, thereby developing learners’ skills and abilities to implement proven water-use efficiencies and water related ecosystem protection practices for 2030 SDGs (Osman et al, 2017). The Associated Schools Project Network (ASPNet) (2009) argues that incorporation of environmental protection and water management in a school curriculum at a secondary level would enable students and teachers to gain valuable knowledge and develop new positive attitudes towards supporting sustainable development.

Drawing on, based on Osman et al (2017) and Ezbakhe (2018), the 2030 SDGs on water-related issues could be achieved through integrating water issues in SDGs agenda; and in classroom setting; and water could well be integrated in the science curriculum.

**Students’ awareness on water related issues.**

There is limited research on secondary students’ awareness of water related issues. Nevertheless, some research shows that Students’ understanding of the nature of water systems is, generally, on a global scale and that they lack awareness of and connection to their own local systems (Covitt, et al, 2009 & Shepardson et al, 2007). Students show lack of knowledge concerning the problems of pollution, the ways to tackle them and the issues related to the management of water resources (Tzaberis & Tzaberi, 2016). There is, however, some evidence that some students are aware of water use, especially those whose parents had tertiary education (Aydogu & Ayslum, 2016). Tertiary students specialising in biological sciences at tertiary level tend to show a more complex understanding of water, in terms of seasonal river flow, water treatment and quality as well as how river water quality is dependent upon both
human activities and natural features (Raymond, 2008). With the study carried in US by Curry (2010), the results showed that students had sound knowledge on water quality issues.

Water related issues could be acquired through learning in class. Schools have an important place within their local communities, to develop the competences of students who of students who live in catchment areas, to solve local issues (Harkary, 1998 & Miller, 1995). Against this background, this study investigated students’ knowledge of their local area water issues, and determined how knowledgeable they were on water related problems and solutions to them by reference to the stream, within the proximity of their school.

Students’ knowledge on rivers and streams.

The formation of Global Rivers Environmental Education Network (GREEN), an international network that seeks to bring students, teachers, and communities in the world closer together through studying and improving the river systems (Stapp, 2000), points to a growing movement to deepen students’ knowledge in streams. The current limited management and protection that lack of management and protection of rivers and streams is concerning since they provide habitat not only for aquatic biota, but also terrestrial of biota (Leighn et al, 2019). According to Williams (1990), students in the US had sound knowledge on water quality of Mississippi river and could practically determine its health and state its importance. A tertiary level study in Malasia, showed that students were aware of river water issues and that they contributed largely in creating awareness and educating the public about conserving rivers and streams and water management (Leng et al,2014).

The inclusion of the rivers and streams in the school curriculum, in the context of Lesotho, could help students understand the significance of rivers and streams in their daily life and to help them take care of their local rivers and streams, and to make informed decisions regarding water usage, pollution control and protection of water bodies.

Conceptual framework.

This study draws its theoretical framework from the water literacy theory. According to Otaki, Sakura & Otaki (2015), water literacy is the ability to feel familiar with water, get actively involved in water and face the issue of water as one’s own issues and brings the bond between people and their immediate environment. Mackenzie (2017) points out that water literacy aims to reconnect people with water through variety of approaches. Water literacy may be divided into the following 3 categories:

- **Practical water literacy** as having the knowledge to ensure the vital amount and quality of water, living water literacy as ability to use water wisely in the home and social space in one’s own backyard and social water literacy as willingness to act responsibly and make reasonable decisions for society as a whole in terms of water usage (Otaki et al, 2015: pp. 37).

Wood (2014) defined a water literate citizen as someone who is informed and knowledgeable about water use and issues and is applying this knowledge to their values and their actions, whether that is achieved actively or subconsciously. Based on this reviewed literature, the key tenets of water literacy may be summarised as follows:
• Knowledge of safety and quality of water.
• Ability to identify related problems and willingly take action to solve them.
• Active involvement in water related issues.

Research methodology

Study design and sampling

The study is situated in the qualitative research tradition (Cohen et al, 2007). It follows a case study design or style of research, focused on a Junior Secondary School, to investigate water literacy level on science students in one high school in Leribe. The employed qualitative study involved the use of open-ended questionnaire to generate the data that provided in-depth insights into the investigated research questions (Eaden et al, 1999). A small scale pilot study was carried out to ensure the construct validity of the questionnaire used in the main study. The population of the main study consisted of 40 form C or grade 10 students. Convenience sampling (Cohen et al, 2007) was used to select the participating students as they were principal researcher’s class.

Data collection

In this study, two sources of data were used: Open-ended questionnaire and a transect walk. The open-ended questionnaire (Cohen et al, 2007) was administered to determine the students’ water literacy; and a transect walk (Chambers, 1999) was taken by the principal researcher to observe the state of the stream, on which the study was based, in order to corroborate the students’ responses. The open-ended questionnaire items were developed such that they elicited learners’ in-depth views on the research questions. The main study participants were 40 Form C students, and 8 students took in the pilot study. With respect to the pilot study, the questionnaire items were tested for clarity and ambiguity and some were subsequently modified.

Table 1: Indicating questions given to students to respond to.

<table>
<thead>
<tr>
<th>Question no</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Does the stream pose any danger to people living around it?</td>
</tr>
<tr>
<td>2</td>
<td>How does the stream benefit the community around it?</td>
</tr>
<tr>
<td>3</td>
<td>How do people who live close to the stream affect?</td>
</tr>
<tr>
<td>4</td>
<td>Is water in the stream clean or polluted? Explain.</td>
</tr>
<tr>
<td>5</td>
<td>Mention any pollutants you have seen in the stream.</td>
</tr>
<tr>
<td>6</td>
<td>What can be done to take care of the stream?</td>
</tr>
<tr>
<td>7</td>
<td>Name two organisms found in clean waters</td>
</tr>
<tr>
<td>8</td>
<td>Name two organisms found in polluted water.</td>
</tr>
<tr>
<td>9</td>
<td>Is dragon fly found in clean or polluted waters?</td>
</tr>
</tbody>
</table>
A transect walk was taken by the researcher, to observe the key features of the local stream on which the questionnaire was based. The stream observation was specifically intended to verify the following.

• The impact of people on the stream

• The level of water pollution in the stream

• The uses of water in the stream by the local community

Data analysis

The study followed both quantitative and qualitative data analysis methods (Kirk, 2013). Qualitative data analysis involved the researchers making sense of data in terms of the participants’ definitions of the situation, noting patterns, themes, categories and regularities (Cohen et al, 2007). The data was also analysed quantitatively by the frequencies of learners’ responses on certain instances. The analysis was guided by the overall aim to investigate science students’ water literacy knowledge in relation to the local stream. The themes emerging from the data were related to the theoretical framework, and to answer the key questions under study.

Findings

Below are the findings of the study, based on the both transect walk and questionnaire.

The transect walk

The key observations made during the walk included the following: the community mined sand from the stream, people drew water from the stream for domestic use; donkeys were used to collect water, the research school occasionally collected water from the stream for different school activities such as cleaning the classrooms, cleaning toilets and some times cooking; livestock drank from the stream. The were many trees along the stream from which people harvested wood for domestic uses; there were many disposable nappies thrown along the stream; used sanitary pads were also found including plastics, papers, bottles and a dog carcass along the stream. A chinese farm which used the stream for irrigation was also observed.

Figure 2 below is a picture showing some of wastes thrown along the stream by the people
Students’ knowledge of the health of their local stream and the associated biological indicators.

To establish the students’ knowledge of the stream health, they were first asked to explain whether or not they thought the stream was polluted.

When asked to explain whether stream water was clean or not, most students (50%) stated that the stream water is not clean. 35% said it is clean, and very few (7.5%) claimed that sometimes it is polluted and sometimes it is clean and 5% said they were not sure. Students’ knowledge on stream health is significant in that the garbage observed along the stream indicated that stream water is not clean.

Table 2. Students’ views on the state of stream pollution

<table>
<thead>
<tr>
<th>Stream water is polluted</th>
<th>Stream water is NOT polluted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ reasons</td>
<td>Number of students</td>
</tr>
<tr>
<td>Thrown dog dead bodies in the stream</td>
<td>6</td>
</tr>
<tr>
<td>People urinating in water</td>
<td>3</td>
</tr>
<tr>
<td>Used nappies left in the stream</td>
<td>9</td>
</tr>
<tr>
<td>Plastics and bottles thrown in the water.</td>
<td>7</td>
</tr>
<tr>
<td>Brown colour of water</td>
<td>4</td>
</tr>
<tr>
<td>Presence of germs in water</td>
<td>3</td>
</tr>
<tr>
<td>Presence of bacteria causing diseases</td>
<td>2</td>
</tr>
</tbody>
</table>
When asked to explain on whether stream water is polluted or not, most students (65%) thought the stream was polluted, and they mentioned a variety of solid waste dumped into the stream as a cause for water to be unclean (see table 2 above). Few students (11%) stated that the cleanliness of water is indicated by the presence of tadpoles in the water.

The figure 4 below shows students’ knowledge of the pollutants found in the stream.

![Figure 4. Percentages of pollutants occurring in the stream](image)

In response to the question on the type of pollutants found in the stream, large number of students (43%) indicated that they had seen remains of dead dog bodies in the stream and along the stream. Equal number of students (12%) identified nappies and the plastics respectively. The least mentioned pollutant (3%) was a fertilizer which is an important chemical pollutant in light of the community fields surrounding the stream.
Students’ knowledge of any two organisms found in clean water.

Students’ knowledge on organisms living in clean water is shown in the pie chart below.

Students were asked to name any two organisms found in clean water in order to determine their knowledge of biological indicators of clean water. Fish was the most frequently mentioned organism (32%). Surprisingly, the least number of students (2%) mentioned tadpole as the organism found in clean water, as tadpole is an indicator of clean water. All other organisms mentioned at varying frequencies, commonly occur in the stream and other streams in Lesotho except for one organism that does not occur in Lesotho streams, a crocodile. All other organisms are correctly mentioned to exist in clean water.

Students’ knowledge of any two organisms that exist in polluted water.

Students’ views on organisms found in their local stream when the stream is polluted.

In relation to students’ knowledge of biological indictors of polluted water, Figure 6 shows that frogs were the most frequently mentioned organisms, at 36%, as found in polluted waters. A crab rated second at 19%, while stone fly was the least organism mentioned to be found in
polluted waters at 2%. The mentioned organisms are not tolerant to polluted waters, except earthworm which is highly tolerant to pollution.

*Students’ association of dragonfly with water quality.*

Researcher observed dragonfly as a common organism flying around in the local stream, the knowledge of students in relating this organism with water quality of the local stream was assessed and the results are shown below.

![Figure 7. Quality of water associated with dragonfly](image)

On being asked whether or not a dragonfly was associated with clean water, most students (60%) correctly stated that dragonfly is found around clean water (see figure 7 above). Fewer students (30%) associated dragonfly with dirty water, and the small percentage (5%) said it occurs in both clean and dirty water. Only 2.5% of the students were uncertain. Students’ knowledge on health of water and associated biological indicators is sound.

*Students’ knowledge of the stream-related socio-economic problems and possible solutions to them.*

Students were further asked to explain any possible danger posed by the stream, in attempt to determine its socio-economic impact on the community. Table 3 below shows students’ responses on the question.

**Table 3 Showing number of students and reasons on possible dangers of the stream.**

<table>
<thead>
<tr>
<th>Danger posed by stream</th>
<th>Number of respondents on stream danger</th>
<th>Number of respondents viewing stream as not dangerous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Washes away people crossing</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Swimming kids drown in the stream</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Floods destroy fields</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
Contribute to low temperatures 3
Waterborne diseases 4
Not sure 2
Small stream 1
Presence of bridge for people 2

From table 3 above, the majority (32) of the students are aware of the dangers posed by the stream to the nearby community. Only 2 students were not aware of the dangers of the stream to the people living around it. One student considered the stream to be small and not dangerous. Two students highlight that the stream is not dangerous as there is a bridge for people to cross. Three students highlighted that stream was not dangerous as houses were far away, it is not included in the table.

The impacts of communities to the stream.

Table 4. Indicating students’ responses on effects of people on the stream.

<table>
<thead>
<tr>
<th>Effects of people on the stream</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throw dead dog bodies in the stream</td>
<td>8</td>
</tr>
<tr>
<td>Throw nappies in the stream</td>
<td>6</td>
</tr>
<tr>
<td>Throw papers</td>
<td>7</td>
</tr>
<tr>
<td>Throw plastics in the stream</td>
<td>5</td>
</tr>
<tr>
<td>People use stream as toilet</td>
<td>5</td>
</tr>
<tr>
<td>Dump wastes in the stream</td>
<td>10</td>
</tr>
<tr>
<td>Pollution by fertilisers</td>
<td>2</td>
</tr>
<tr>
<td>Not sure</td>
<td>1</td>
</tr>
</tbody>
</table>

From table 4 above, nearly all the students are aware of the effects of the communities on the stream. Only one student was unsure of effects to the stream. Generally, many stated that people living around the stream have turned the stream into a dumping site. This is in line with what the researcher observed in the stream during transect walk.

Students’ knowledge on how to take care of the stream.

A question was posed to determine the students’ knowledge of possible “care for their local environment”. They were asked identify local environmental problems, their causes and suggestions of solutions to them as required by the syllabus.

Table 5: Students’ suggested strategies of caring for the stream

<table>
<thead>
<tr>
<th>Strategies of caring for the stream</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop throwing pollutants in the stream</td>
<td>19</td>
</tr>
<tr>
<td>Arresting people polluting the stream</td>
<td>2</td>
</tr>
</tbody>
</table>
Recycling waste materials 1
Burying waste materials 2
Fencing the stream 6
Planting trees around the stream 6
Teaching people about pollution control 1
Teaching people about importance of the stream 1
Forming organisations for pollution prevention 1
Cleaning the stream 1
Written signs on notice board about stream pollution prevention 1

From table 5 above, all students gave views on how to take care of the stream; and a variety of reasons were given. The most frequent strategy mentioned, by 19 students, was that people should simply stop throwing pollutants in the stream.

**Discussions**

*Knowledge of safety and quality of water.*

This principle of Water Literacy describes the knowledge students have on the safety and quality of the water. Water quality is the suitability of water for drinking, recreational use and as a habitat for aquatic organisms and other wildlife (Zamara & Blinn, 2010). In line with this principle set out to investigate, the first research question: “What is the students’ knowledge on the health of their local stream and associated biological indicators?” The results reveal that majority of the students are aware of the occurrence of water pollutants in the stream and have knowledge of health of their stream and could state organisms found in clean water and most students, correctly, associated dragon fly with clean water. They, however, had limited knowledge on the organisms found in polluted waters. The findings are consistent with Curry (2010) findings in the United states which indicated that students had sound knowledge and understanding of water quality issues. The results also are in agreement with Williams (1990) results which showed that science students were knowledgeable about the state of the nearby Mississippi river and could describe the health status of the river. However, of interest is the variance of students in the present study with the tertiary students in the US, in Eldridge-Fox et al (2010) study who found that students had low water literacy, and could not even say what their sources of water is in the campus.

*Ability to identify water-related problems and willingness to take action to solve them*

This water literacy principle underpins the second research question: “What is the students’ knowledge on the stream-related socio-economic problems and possible solutions to them?” The findings indicate that many students have significant knowledge of their local stream problems and possible solutions to them. Thus, the findings differ from those of Tzaberis & Tzaberis (2016) on the study carried out in Greece. Their results indicated that students showed significant lack of knowledge concerning the problems of water pollution and the ways to tackle them. The students’ knowledge of the water problems, further corroborates the students’
“connectedness and familiarity with water”, as indicated under the water literacy principle above. Moreover, the findings are at variance with those of Eshaqu and Al-Khaddar (2008), who found that students in their study lacked knowledge on water related problems (water shortage) concerning their country. The study results are in line with Mutisya and Barker (2011) whose findings showed that students were aware of the key environmental issues in their local area and they also understood the causes of some of these environmental issues and their solutions.

Conclusions and recommendations

Water education in Lesotho, in the context of secondary school science, can play an important role in connecting students to their local environment and in helping students to be part of the solutions to the Lesotho existing water-related problems. However, some important content on water literacy such as water quality and safety, knowledge of water sources, connectedness and familiarity with water and efficient uses of water is not explicitly reflected in the science syllabus and science textbooks. Previous studies have indicated that students’ knowledge on water is at global level and not at local level. This study too, shows that students’ water literacy about their local stream is limited in many aspects. This could be the case for many other students. Water is one of the important 2030 Sustainable Development Goals (SDGs) that need to be addressed and is stated in SDG 6, ‘Clean Water and Sanitation’ and SDG 14, ‘Life Below Water’, and schools can address local stream water, in relation to the above mentioned two SDGs, and in combination with SDG 4, on ‘Quality Education’, with the aim of achieving the goal of clean water for all by 2030. Sound knowledge on water is found to be more on educated individuals than the uneducated ones (Wang et al, 2018). For information to reach to the community effectively, the correct place to start from is schools. What could be done to improve water literacy in schools in Lesotho? The miniSASS tool could help connect students to their local stream so as to promote their water familiarity and awareness on water related issues.

The study established level of the knowledge of the science students on water literacy in relation to their local stream. Based on the findings, the following recommendations are therefore put into place:

1. Further studies should be undertaken in large scale involving many students and their local streams, as this one involved few students in one class from one school and therefore conclusions cannot be generalised for the whole country.

2. The Lesotho Curriculum and Assessment Policy should explore the value of miniSASS as one of the tools which could help connect students and their local water streams.

References


Zamara, D. & Blinn, C. (2010). Water quality and quantity
OPERATIONALIZING THE GRAND PCK RUBRIC: A CASE OF DEVELOPING A CLASSROOM RUBRIC FOR PORTRAYING eTSPCK IN CHEMISTRY

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University of the Witwatersrand,

Abstract

This study outlines the development of a rubric to portray the quality of enacted Topic Specific Pedagogical Content Knowledge (TSPCK) in classroom teaching. The rubric is based on the observation of visible TSPCK component interactions in enacted lessons. Primary data were the observations of two consecutive lessons of three experienced physical science teachers, which were video recorded. Teacher interviews complemented the data. The analysis process entailed in-depth qualitative method capturing displayed TSPCK episodes and providing thick descriptions of their characteristics by three raters. These were in turn, translated into criteria for the emerging TSPCK quality categories. The reliability of the rubric was further established through the Kappa-Cohen inter-rater reliability index calculated at 0.82, 0.82 and 0.80, respectively. The resulting analysis led to the formulation of a comprehensive, more sensitive 5-quality category rubric with the option to refine it into an overview rubric with 3 category rubrics.

Keywords: Pedagogical Content Knowledge, Topic Specific PCK, TSPCK classroom rubric

Introduction

Pedagogical Content Knowledge (PCK) remains a useful theoretical construct to describe professional teacher knowledge for teaching science. Shulman referred to it as the category of professional knowledge base for teaching that embodies the aspects of content most germane to its teachability (Shulman, 1986, p. 9). PCK has found its use in many science Initial Teacher Education (ITE) (Henze & Barendsen, 2019) programmes and also in-service teacher programmes (Loughran, et al., 2012), thereby raising the need to define and capture its quality. Previous studies argue that the process of capturing and portraying PCK is a challenging endeavour due to its tacit nature (Aydeniz & Kirbulut, 2014). The recent systematic literature review on PCK rubrics (Chan et al., 2019) reflected the existence of at least 26 PCK rubrics most of which measure the quality of static (thinking and planning) PCK and only a handful measuring the dynamic PCK, which is associated with classroom enactment. Several benefits have been suggested for using scoring rubrics in performance assessments. These include increased consistency of judgment when assessing performance and authentic tasks, and providing valid judgment of performance assessment that cannot be achieved by means of conventional written tests. Scoring rubrics are further said to have the potential to promote quality teaching and learning (e.g. Jonsson & Svingby, 2007) by making expectations and criteria explicit, which also facilitates feedback and self-assessment. It therefore follows that a well-designed PCK rubric should reflect definitions of the key features of PCK for measurement by demarcating the scope and range of the construct. Thus enabling guidance for
the analysis of performance. The interest of this study was to develop a rubric that is practical and easy to use in assessing the quality of teachers’ enacted Topic Specific PCK (eTSPCK).

A Review of PCK Rubrics

Several science education researchers have over the years devoted studies on characterizing PCK and by extension Topic Specific PCK (TSPCK) (e.g. Alonzo & Kim, 2016; Gess-Newsome et al., 2019; Loughran et al., 2006). In a more recent development emanating from the second PCK Summit held in the Netherlands in 2016, Chan et al. (2019) conducted a study determining considerations of constructing a grand rubric for measuring the quality of science teachers’ PCK. The grand rubric is to be used to determine all variants of PCK as depicted in the Refined Consensus Model (RCM) (Carlson et al., 2019). Using a systematic literature review of existing PCK rubrics in science education, Chan et al. (2019) made reference to five distinct features. Among these, and of interest to this study are: (i) the observation that the structure of PCK rubrics that are based on specific PCK models is typically comprised of PCK components as dimensions and quality descriptions in an x-y kind of a plane. Furthermore, (ii) the quality descriptors are grounded within the constructivist view of teaching and learning. The most common criteria were conceptual approaches, sense-making and teaching for meaning in almost all the rubrics reviewed. The awareness of student thinking, student-centred approaches, and links between student ideas and teaching strategies were next in popularity. Another recurring theme was the quality of pedagogical reasoning and the degree of integration between PCK components. These quality descriptors were observed largely from PCK rubrics that measured planned PCK, using pen and paper kind of responses. While rubrics that measured enacted PCK were found to be in the minority, they however, (iii) all drew their data from video recorded lessons and lesson observations. In addition to the findings of the systematic literature review, Chan et al. (2019) complemented the data with transcribed discussions of the PCK Summit II sub-group on measuring and capturing PCK. Key features elicited from the PCK Summit sub-group discussions were the consideration for the importance of component interactions, pedagogical reasoning that informs the observed actions in a classroom. Furthermore, the sub-group emphasized the importance of using several data sources to triangulate the findings from using a rubric. Resulting from the study was a grand PCK rubric template comprised of five PCK components as shown in Table 1. While Chan et al. (2019) acknowledge that the five PCK components were not explicitly articulated in the RCM, they however, regard them as reflecting acceptable content validity as they were generated from the discussions by experts.

Table 1: The PCK components used in constructing a grand PCK rubric (Chan et al., 2019)

<table>
<thead>
<tr>
<th>PCK Component/feature</th>
<th>Description of the component/feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge and Skills Related to Curricular Saliency.</td>
<td>Appropriate selection, connection, and coherence of big ideas; accuracy of content.</td>
</tr>
<tr>
<td>Knowledge and Skills Related to Conceptual Teaching Strategies.</td>
<td>Selecting and using appropriate instructional strategies; using multiple representations.</td>
</tr>
<tr>
<td>Knowledge and Skills Related to Student Understanding of Science.</td>
<td>Identifying and acknowledging variations in student learning and eliciting and assessing student difficulties and misconceptions.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Integration between PCK Components.</td>
<td>Monitoring and adjusting teaching practice based on student feedback and learning of the big ideas as well as the classroom context.</td>
</tr>
<tr>
<td>Pedagogical Reasoning.</td>
<td>Providing a rationale for teacher decision-making and actions within the context of their teaching situation.</td>
</tr>
</tbody>
</table>

The generation of a PCK rubric template with explicit PCK components as shown in Table 1, is a major milestone in the PCK literature, as the evaluation of studies across different contexts and countries may now be conducted with consistency. While Chan et al. (2019) articulated the use of these PCK components in the measurement of teachers’ PCK in different dimensions of PCK, the authors however did not provide the needed criteria that would differentiate the depth and scope of the observed teachers’ PCK quality. In this paper we thus build on this foundational work, and develop a comprehensive rubric to portray the quality of teachers’ PCK.

**Conceptualization of the Rubric**

**Defining the unit of analysis**

The conceptualization of the rubric for portraying the quality of the teachers’ enacted PCK was grounded on the idea of evidence of transformation of content knowledge in the specific topic being taught. It then follows that the appropriate grainsize of PCK is at the grainsize of a topic (Carlson et al., 2019), called Topic Specific Pedagogical Content Knowledge when displayed in the lesson as eTSPCK. TSPCK has been defined previously (Mavhunga & Rollnick, 2013), to be comprised of five content specific TSPCK components identified by Geddis and Wood (1997) from which transformation of content knowledge emerges. The authors identified: (i) the knowledge about learners’ prior knowledge, preconceptions, misconceptions and alternative conceptions about a topic; (ii) most important core concepts to be understood and their relations to prior concepts in the discipline, concept sequence and knowledge which they called curricular saliency; (iii) areas likely to pose potential difficulty for understanding by learners termed What is difficult to understand. Knowledge of this components generates dedicated awareness of such areas; (iv) representations specific to the topic, which include examples, illustrations, analogies, simulations and models that are appropriate for teaching various concepts of the topic and (v) conceptual teaching strategies for the topic that take all of the above components into consideration.

It has been reported repeatedly that when these components are used interactively in a teacher response, for example in a lesson (Aydin et al., 2014), or in planning to teach (e.g. Rollnick et al., 2017) the teacher’s TSPCK comes into view. This understanding is supported in recent research (Mavhunga, 2020) reporting that specific teacher tasks promote the visibility of the teacher’s TSPCK. These are when a teacher responds to a learner’s misconception; provides a summary of most important content in a lesson and also when relaying a teaching sequence or a conceptual teaching strategy. It was therefore reasonable to regard TSPCK component
interactions as the unit of analysis to be tracked in a lesson and be captured. Typically, in a lesson, TSPCK component interactions moments are bound to happen more than once and also at different points in a lesson. Therefore, it became more practical and authentic to aim to portray the captured TSPCK component interactions in the sequence of their emergence into what would be the teacher’s TSPCK profile for the lesson, rather than adding up the visible component interactions, as a mathematical sum of some sort. With the conceptualization of the unit of analysis for TSPCK in place, the next phase was to develop the basis for defining quality.

The basis for differentiating quality
Several science education researchers (Aydin, Demirdogen, Atkin, et al., 2015; Park & Chen, 2012) have pointed to the extent of PCK component interaction to reveal the measure of the quality of the PCK displayed. We built on this understanding and extended it to imply such interactions to inform the quality descriptions. What was however not known at the beginning of this process were the permutations and formats in which the TSPCK component interaction occurs in classroom practice, and whether these differ enough to distinguish the varying extents for the formulation TSPCK quality categories. We contended that a teaching segment that demonstrates component interaction in a lesson would show explicitly how a teacher uses these components interactively in a particular time. Such a teaching segment we referred to as a ‘TSPCK episode’. The idea is taken from Park and Chen (2012), who provided an operational definition of a PCK episode as a performance where at least two components of PCK interact to support teaching. Similarly, a TSPCK episode is described in this study as connections between two or more of the content-specific components used in defining TSPCK. We turned to observing the lessons delivered by experienced practicing teachers considered experts in teaching chemistry topics. It is commonly expected in the PCK literature that expert teachers have PCK, and the quality of their PCK is likely to be good by virtue of their reflective experience in the field and are likely to demonstrate episodes of TSPCK in their teaching. Therefore, to determine possible differing extents through which TSPCK components interact, in the TSPCK episodes and the likeliness of observing sophistication in the component interactions, it was best to observe the teaching of expert teachers.

In order to portray the identified TSPCK component interactions in a lesson, we reproduced the identified TSPCK episodes pictorially as TSPCK maps. A TSPCK map is a visual display that describes the nature of the connections among the interacting TSPCK components found present in an identified TSPCK episode. In this study, the visual display includes the name and quantity of the components found interacting, the teaching task from where the TSPCK episode has been extracted, represented as a rectangular box, a platform onto which the TSPCK episode is depicted, see Figure 1 below.

**Figure 1**: A sample TSPCK Map
The understanding for differentiation of the quality of teachers’ eTSPCK was further informed by two principles for development of functional rubrics. The first is based on the emphasis that Moskal and Leydens (2000) place on the importance for criteria of a rubric to spell out the qualities that need to be displayed and regarded as reflecting proficient performance. The second principle, proposed by Arieli-Attali and Liu (2015), calls for the measurement of the proficiency of a performance to be described from spelling out the desirable behaviour of the components of the construct. That is, what constitutes proficiency should be described from the behavioural perspective of the components that make-up the construct being measured. In this study, both authors’ views were adopted and interpreted to point at a need to not only use the components of TSPCK in the measurement for quality but to also spell out explicitly the way in which the behaviour of the components of the construct of TSPCK reflects the different quality categories of the teachers’ eTSPCK.

The literature points, among others, to two broad different approaches for developing quality categories in rubrics. One is an approach where the categories and the items are pre-constructed from a well-established based knowledge (Arieli-Attali & Liu, 2015). For example, a concept-based kind of a categorical rubric serve the purpose of making explicit two distinctions: (a) among the incorrect responses, the type of error or misconception identified; and (b) among the correct responses, the type of strategy or a conception evident in the response. The second approach is to generate the qualities and the associated criteria from real life experiences that demonstrate proficient performance (Chan et al., 2019; Moskal & Leydens, 2000). The second approach was adopted as in this case there was no correct and incorrect teaching performance, bearing in mind that in teaching there is rarely a single correct way of teaching. The identification of component interaction (TSPCK episodes) by definition is confirming the presence of proficiency, what is however still missing is a description of its level. In this approach, the levels of the scoring criteria for the scoring rubric are described by first establishing the top level performance. After the top level of performance criteria has been defined, the evaluator may move on to define the criteria for the lowest level of performance (Chan et al., 2019). This is the type of performance that suggests the most limited understanding of the concepts that are being assessed. The contrast between the criteria for the top-level performance and bottom level performance would then suggest appropriate criteria for the middle level of performance. This approach results in three score levels, but if there is a need for greater distinctions, then comparisons can be made between the criteria for each existing category score level. The criteria to constitute a level is decided based on experience and knowledge of the construct, whether it is best to consider a level comprised of few specific lists of points that are evaluated individually or collectively to make a decision. Evaluation based on the individual criteria in a level would mean the rubric is analytic, while evaluation of the listed criteria collectively would mean the rubric is holistic. If an analytic scoring rubric is created, then each criterion is considered separately as the descriptions of the different score levels are developed. This process results in separate descriptive scoring schemes for each evaluation factor. For holistic scoring rubrics, the collection of criteria would be considered throughout the process of construction for each level of the scoring, resulting in a single descriptive scoring scheme. In this study we opted for the development of the holistic version as it is congruent with the idea of interactions among TSPCK components rather than
individual component performance. Reference was further made to the four qualities of a good rubric advocated in the work of Brookhart (1999), which are: (i) having fewer and meaningful score categories; (ii) mutual exclusiveness of the categories; (iii) use of a set of anchors or key words/labels as a reference to assist raters during the scoring process; and (iv) involving independent raters to validate the descriptions in the scoring rubric.

**Methodology**

The participants in this study were three (3) practicing physical science teacher. The teachers were in 3 respective schools considered equivalent by virtue of school type as derived from the historical formulations of the School system in South Africa. The three teachers were considered expert by virtue of their reflective experience in the field (see Table 2), having taught the same subject science in the same Grade for more than six years, and highly spoken about by their peers. Each teacher had two teacher qualifications.

**Table 2: Bio-demographical information of the expert teacher participants**

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Qualification</th>
<th>Number of years teaching physical science</th>
<th>Type of School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atas</td>
<td>B Ed &amp; Dip Edu</td>
<td>7</td>
<td>Township</td>
</tr>
<tr>
<td>Laurent</td>
<td>BSc &amp; B Ed</td>
<td>6</td>
<td>Township</td>
</tr>
<tr>
<td>Charlie</td>
<td>B Ed &amp; Dip Edu</td>
<td>8</td>
<td>Township</td>
</tr>
</tbody>
</table>

Note: Pseudonyms were used to conceal the identities of the expert teachers who participated in the video-recorded classroom lessons

As argued in the literature, the theoretical construct of PCK is widely understood to be developed with extended time, characterized by trial and error, teacher-reflections, and re-teaching a particular topic (Bishop & Denley, 2007; Magnusson et al., 1999). Thus, the observation of practicing teachers well-spoken by peers was rational. Primary data for the development stage was thus derived from observations of two consecutive video recorded classroom lessons for each of the three practicing teachers. Both teachers were observed teaching the topic of stoichiometry, targeting the “Big Idea” of the mole to Grade 11 learners. The data collected was further complemented with stimulated-recall teacher interviews to achieve triangulation.

**Analysis**

The analysis of the recorded video lessons and transcripts captured from the classroom practice of the three expert teachers happened in two stages. The first stage involved watching and re-playing the video-recorded lessons several times and looking for evidence of moments (teaching segments) that demonstrated the presence of eTSPCK episodes. This task was carried out by the authors with the assistance of a reference team of 3 independent raters familiar with TSPCK and the method. Once confirmed, the identified teaching segments containing eTSPCK episodes were analyzed in-depth and the sequence of their emergence in a lesson noted. The analysis entailed first describing the TSPCK components found interacting and their quantity. This was followed by the descriptions of the complexity of the nature of the
interactions (Mavhunga, 2020). An inter-rater reliability agreement between rater scores was calculated at a Cohen Kappa value of 0.82, 0.82 and 0.80 across the respective teachers, which was considered acceptable.

Findings

Table 2 below shows the number (quantities) of TSPCK episodes identified in the different teaching segments for each teacher.

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Quantity of TSPCK Episodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atas</td>
<td>5</td>
</tr>
<tr>
<td>Laurent</td>
<td>4</td>
</tr>
<tr>
<td>Charlie</td>
<td>4</td>
</tr>
</tbody>
</table>

The analysis of the video-recorded lessons revealed a total of 13 TSPCK episodes. The purpose of analyzing the video-recorded lesson transcripts was however not to compare the teachers, but to capture the kind of TSPCK episodes they display. This was in order to establish emerging categories, that would in turn be used create the levels of quality in the rubric.

On close examination, diverse patterns thematically emerged from the analysis of 13 eTSPCK episodes into themes sorted by quantity of interacting components found in a TSPCK episode, the nature of complexity of their interactions and the type of teacher tasks the TSPCK episode emerged. Across the 13 eTSPCK episodes, were two-, three- or four- different component episodes in some cases with versions of one component found repeated in the mix. The TSPCK component interactions were found to interact in form of either a interwoven component interactions or a combination of interwoven with a linear link. As alluded earlier, interwoven interactions are episodes where the teacher explains a concept by moving in and out of two or more components. A linear sequence, on the other hand, refers to components in a TSPCK episode that are used one at a time in a linear sequence, one after the other. Sample extracts of teaching segments with TSPCK episodes displaying different quantities of TSPCK component interaction formats are shown in Figures 2-6.
**Figure 2:** 2-component TSPCK episode with interwoven interactions

**Video extract from Teacher Charlie: Intervenon /Linear 3-component TSPCK Episode**

**Teacher:** "We have realized that there is a relationship between mass and the mole. The bigger the mass the bigger the quantity of the substance-mole. The teacher repeats this statement. This means if we know the mass of a substance, we can calculate the number of moles of that substance (CS). The teacher then derives the formula for calculating the number of moles of water, on the chalkboard: \( \text{mass} / \text{molar mass} \) (symbolic: RP), and asks learners to use the formula to work out the number of moles for the different masses of the substances they had weighed earlier in their groups. **Teacher:** Are you getting the same number of moles? What is the same here?” "I was talking about the mole. I don’t mean mass or volume, I mean mole [n] a scientific unit of measurement (LP). The explicit emphasis of the meaning of mole not to refer to mass or volume but a unit of measurement is evidence of understanding of common misconception about the topic which indicates presence of the component of Learner Prior Knowledge (LP).

**Corresponding TSPCK Map**

In this segment three components: Curricular saliency (CS). Representations (RP) and learner prior knowledge (LP) are used evidently and interactively in both an interwoven and a linear standalone sequence formation.

In the segment, the teacher begins by explaining the relationship between mass and number of moles (CS). He then introduces an equation, to show the relationship between mass and number of moles (RP). He allows learners time to apply the equation, before finally summarizing the meaning of mole, by emphasizing how it works. An indication of understanding a common misconception about the topic (LP).

**Figure 3:** 3-component TSPCK episode with interwoven interactions with a linear link

**Teacher:** "It is very difficult to measure the mass of a gas... For gases we use volume”. The teacher displayed a visual slide depicting the different volumes of gases formed during electrolysis of water, as indicated below.

He simultaneously wrote the reaction equation for the experiment on the chalkboard: \( 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \) (RP) which he used to link the mole ratio of reactants and products to the resulting molar gaseous volumes of the products over the slide.

**Teacher:** “From the balanced equation, we expect hydrogen gas to be twice as much oxygen. From the (mole: mole:vol:vol) ratio (2:1) this means that the relative molecule ratio of the equation or the relative moles of reactants and products give us the mole volume ratio of reactants and products.”

He posed several questions. Teacher: which of the two gases would be more Hydrogen or oxygen. What does the equation tell us?” (WD). He then derived an equation on the chalkboard, which he used to relate the number of moles, volume and the Avogadro’s constant (RP). The teacher finally explained the meaning of mole, stating that, the amount of substance in science gives us an idea about the number of moles of a substance. Particles contained in the substance can be used as a counting unit. We can also use the number of moles of various reactants to determine the products in our industries and everyday life (CS).

**Figure 4:** 3-component TSPCK episode with 1 component repeating
As shown in Figures 2-6, the nature of the component interactions was either completely interwoven or a combination of interwoven with a linear link to 1 other component or a set of multiple components that is also in an interwoven interaction. Furthermore, 3- and 4-component TSPCK episodes were observed to have versions where one of the components is repeated bringing some additional depth into the teacher explanation (See Figures 4 and 6).
The repeating element in an episode of TSPCK component interaction was viewed as making a noticeable difference in the explanation by enriching it with an additional insight. For instance, Gabel (1998) advocates for the teaching of chemistry concepts using three levels of representations simultaneously. The author emphasizes, scaffolding of learning through showing concept manifestation in real physical visual display, and how this may be represented symbolically from the chemical equation perspective, or even graphs, as well as how the microscopic particles actually behave to demonstrate the concept. The simultaneous use of representations at the different levels of explanation in most of the episode analyses above was seen to bring about some added benefit in the depth of the explanations, and hopefully an improved chance for learners to understand. The repeated component appeared to allow the teacher to go deeper into the understanding of the given explanation. Based on these emergent observations, five quality categories of TSPCK episodes emerged as presented in Figure 7.

<table>
<thead>
<tr>
<th>Simple</th>
<th>Moderate</th>
<th>Proficient</th>
<th>Exemplary</th>
<th>Sophisticated</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teaching segment.</td>
<td>- Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teaching segment.</td>
<td>- Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teaching segment, but with one component repeating bringing in additional depth that complements the initial emergence.</td>
<td>- Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teaching segment.</td>
<td>- Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teaching segment with one component repeated in a manner that brings different levels of sophistication (e.g. representations used at all three levels: macro, symbolic and sub-microscopic levels).</td>
</tr>
<tr>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component.</td>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component.</td>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component, or a set of interwoven multiple components.</td>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component, or a set of interwoven multiple components.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 7:** Five categories eTSPCK rubric for scoring TSPCK in action

It is important to make clear how certain decisions were made in creating the presented quality categories in Figure 7. As mentioned earlier, we considered the visible evidence of TSPCK component interactions firstly, to confirm the presence of TSPCK and secondly, the extent of the component interactions to be revealing the quality of the demonstrated teachers’ TSPCK. It was observed that when the presence of component interactions is examined, the increasing quantity of different components in an episode evidently demonstrated increasing levels of PCK quality. This was observed to be true even when one of the components is repeated more than once in a given instance. This observation is in line with other empirical findings, which argue that the quality of PCK in a topic is demonstrated by the extent of the synergistic
interactions of the specific components of PCK and by extension TSPCK (Aydin, Demirdogen, Akin, et al., 2015; Park & Chen 2012). However, beyond the examination of the extent of the synergistic component interactions by quantity, we could not identify any strong difference in the quality of TSPCK episodes on the basis of the type of format or structural component interactions, be it either the completely interwoven format or interwoven with a linear link format. Thus, it was agreed that the nature of the structural format of the component interactions could not be used as criteria to distinguish quality across the identified TSPCK episodes. However, it was agreed that it should be included in each category to complete the description of the component interactions displayed. Figure 7, presents what we considered to be a very comprehensive rubric with five TSPCK quality category levels, sensitive to distinguishing the difference in quality afforded by a repeating component on one of the episodes characterized by equal number of different TSPCK components present.

Re-calling some of the principles of developing efficient rubrics, Brookhart (1999) pointed to the operational value for rubrics to have (i) fewer and meaningful score categories; (ii) mutual exclusiveness of the categories; (iii) use of a set of anchors or key words/labels as a reference to assist raters during the scoring process. It was in this context that the 5 quality categories of the rubric were refined further.

**A simplified version**

The refinement process entailed going back to re-watch the video and paying more attention to the identified TSPCK and their corresponding analysis. Such a closer look revealed that there is a convincingly noticeable difference in the descriptive criteria of the simple TSPCK (the first category) and the sophisticated TSPCK category (the last category) in line with suggestions for rubric construction by Moskal and Leydens (2000). However, the differences between TSPCK episodes with the same number of interacting components brought about by the observed repeating components, as displayed in the moderate vs the proficient categories as well as the exemplary and sophisticated categories, could be merged to create three quality categories that are strongly distinct from each other as shown in Figure 8.

<table>
<thead>
<tr>
<th>Simple</th>
<th>Proficient</th>
<th>Sophisticated</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Evidence of two different TSPCK components interacting evidently and distinguishably in a specific teaching segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The components interactions maybe interwoven or have a linear sequence structure format</td>
<td>- Evidence of three different TSPCK components interacting evidently and distinguishably in a specific teaching segment.</td>
<td></td>
</tr>
<tr>
<td>- One of the components maybe repeated in the same TSPCK episode bringing in additional depth in teacher explanations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component.</td>
<td>- Evidence of four different TSPCK components interacting evidently and distinguishably in a specific teaching segment.</td>
<td></td>
</tr>
<tr>
<td>- One of the components maybe repeated in a manner that brings different levels of sophistication (e.g. representations used at all three levels: macro, symbolic and sub-microscopic levels)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The components interactions maybe totally interwoven or a combination of an interwoven structure with a linear link to another different component, or a set of interwoven multiple components.</td>
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</table>

**Figure 8:** A Simplified version of the eTSPCK rubric
The simplified version of the eTSPCK rubric distinguishes the quality of TSPCK demonstrated strongly by the quantity of the components seen interacting in a teaching segment. This move meant that the simplified version has lost the sensitivity to differentiate between TSPCK episodes with equal number of components as seen derived in the holistic rubric with 5 categories. It however delineates a spectrum of performance levels that may be sufficient for measuring the quality of teachers’ eTSPCK in certain contexts where establishing an overview would be sufficient or in studies tracing shifts in the teachers’ eTSPCK.

It is however, important to also note that the newly developed eTSPCK rubric, different to analytical rubrics, has a limitation in that it will not lead to a neat calculated single score describing the quality of the demonstrated performance. Partly because not everything that happens in a classroom is evidence of TSPCK, thus the mere presence of TSPCK episodes in the teachers’ lesson is a reflection of some level of quality. The rubric thus serves to identify, capture and portray the quality of the various moments of eTSPCK manifestation in a lesson. The captured eTSPCK episodes could be portrayed with description of their quality category as scored from the rubric in the sequence of their emergence to create an eTSPCK teacher profile presenting the big picture. Judgement could be read and inferred from the presence and quantity of high scoring category TSPCK episodes in the profile. Examples of the suggested eTSPCK profile construction are presented in Figure 8. These are samples based from using the simplified eTSPCK rubric. When the captured teacher eTSPCK episodes are portrayed in a teacher profile as shown in Figure 8, a big picture of the teachers’ performance is readily made more visible. Drawing from the evidence seen about the enrichment of the teachers’ explanations when a high quantity of TSPCK components are found present in a teaching episode, it is reasonable to expect teacher eTSPCK profiles with the presence, and a high quantity of high order quality episodes to be judged as displaying a high quality of eTSPCK.

![Teacher TSPCK profile with less high quality category TSPCK episodes](image1)

![Teacher TSPCK profile with more high quality category TSPCK episodes](image2)

**Figure 9:** Sample teacher TSPCK episode profiles
Discussion

This study sought to develop a rubric that can be used to capture and portray the quality of teachers’ enacted TSPCK. The process of construction was based on the principles advocated in the construction of a grand PCK rubric as demonstrated by Chan et al. (2019) emanating from the second PCK Summit in 2018. The grand PCK rubric, advocated for the use of the components of PCK as quality indicators of the construct to be measured. This view, as alluded earlier, has also been purported by Arieli-Attali (2015), who succinctly valued the use of the behavior of the components of a construct in formulating indicators for the measurement of its quality. We supported this view as it strengthens the arguments for the construction of theoretical constructs that have conceptual definitions congruent to the quantitative ways of measuring it. We further noted the close match of the operational knowledge components of PCK identified by Chan et al. (2019) and the participating experts to the components of TSPCK used in this study. These knowledge components have been argued for as key to the emergence of transformation of content knowledge (Geddis and Wood, 1997). While Chan et al. (2019) included component interactions and pedagogical reasoning (teacher action justification) as part of the components of PCK to be used, we argued in this study rather for regard of component interactions as the succinct feature that describes the behavior of components giving rise to criteria for different quality categories by virtue of their varying extents. Applying this understanding as a lens to analyze the video recorded lessons of practicing teachers gave rise to the construction of both a comprehensive eTSPCK rubric with high sensitivity as well as a simplified version. The comprehensive rubric could be useful in contexts targeting the promotion of the quality of teaching and learning, in a sense that it makes expectations and criteria explicit, thus able to facilitate formative, peer and self-assessment. While the simplified version may be useful in contexts where initial screening of performance is useful for a given purpose. Both these versions share the same TSPCK components that are serving as quality indicators, thus rendering the rubric versatile for different needs, yet retaining the derived compatibility for possible comparison of findings to other PCK equivalent studies.

Conclusion

Notwithstanding the limitations pointed above, the findings are encouraging for the value to be derived from the newly developed eTSPCK rubric. The successful development of the eTSPCK rubric from the considerations espoused in the development of a grand PCK rubric validates the objective of the grand rubric as a generic template since it is designed to be customized to each setting. Furthermore, the newly designed eTSPCK rubric can be used with multiple data sets as it is built on the considerations linked to the RCM informed by best practice found in the PCK literature. We hope that the newly designed eTSPCK provides the science education community with a tool for use in explorative studies determining impact of developmental initiatives on the quality of teaching of both preservice teachers and in-service teachers.
Acknowledgements

Financial support from the National Research Foundation (NRF) of South Africa through the Human and Social Dynamics in Development (Grant 111799) is highly appreciated and acknowledged.

References


HOW SECONDARY STUDENTS USE SELF-REGULATION IN LEARNING BIOLOGY

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Chancellor College, University of Malawi

Abstract

The paper reports on a study which explored how secondary students use self-regulation whilst learning biology. An instruction model that aims at fostering the development of self-regulation called, Plan, Organise Monitor and Evaluate (POME), was used to develop a questionnaire to find out what self-regulation strategies students use and how these varied with gender and years in school. The questionnaire was augmented with face-to-face interviews. 385 students from four boarding schools in Zomba responded to the questionnaire and a total of 16 students were interviewed. The findings showed that whilst both year 9 and year 11 students reported the use of plan, organise and monitor strategies, there was not much difference between year 9 and year 11 students, suggesting limited development over the secondary school years.

Keywords: Self-regulation, Metacognition, learning strategies, Plan, Organise, Monitor, Evaluate

Introduction

As with mathematics, chemistry and physics, biology is compulsory in the science streams in Malawi, and its topics include plants, animals, microorganisms, environment, human biology, genetics and evolution. Most students expect to do well in biology on the Malawi School Certificate of Education (MSCE) but are disappointed with their performance. A study of students’ subject preferences showed that students choose physical science and mathematics as science subjects they liked and performed best at, leaving out biology (Mbano, 2015).

Students perceive different subjects as easy or difficult because of various reasons such as relevance to everyday life, its abstract nature, and the way it is being taught and examined, and how they study it (Etobro and Fabinu, 2017). In general, biology is perceived to be easy since it deals with familiar concepts related to living things and the syllabus is spiral in nature, revisiting the same concepts over and over at an ever increasing depth. Furthermore biology as a school subject does not require complicated equipment for practical work. The schools in Malawi have available several biology textbooks, both local and international. All this leads most learners to expect better performance on MSCE than in other science subjects.

There have been a number of studies on how learners in Malawi schools study science. Mbano (2015) studied students’ perceptions of how science is taught and their preferred teaching strategy. The students indicated that they were frequently taught by copying notes, reading and writing, discussion and using textbooks in class and they felt they learnt more from teacher explanations, reading and writing and teacher notes. Furthermore, Dzama (2006), in a study focusing on student learning strategies in physical science, found that one of the causes of poor performance in science subjects among secondary students in Malawi was the lack of
knowledge of learning strategies that they can use to learn science. The commonly used strategy was memorisation. Similarly, Ngwira (2011), using the Learning and Study Questionnaire (LASQ) found that most students in secondary schools in Malawi employ rehearsal strategies that reinforce simple memory rather than critical thinking or mastery of concepts. This study takes this further by asking the question of how students use self-regulation in learning biology.

Research questions

- What strategies of self-regulation do students use as they learn biology?
- What differences are there in the use of self-regulation between boys and girls?
- What differences are there in the use self-regulation between students in different years?

Conceptual framework

The study is about the use of self-regulation in learning biology. Self-regulation as a concept was developed by Zimmerman from Bandura’s work on social cognitive theory. In his theory Bandura (1986) identifies three factors important in understanding human behaviour, namely; environmental, personal and behavioural factors (Bandura, 1986). Salter (2012 summarises this as:

> People are viewed not merely as reactive organisms acting on instinct and impulse, but as self-organising, self-reflecting beings affected by the social conditions and cognitive processes they experience. (p 2)

Self-regulation is generally seen as a cyclic process comprising planning, performing and reflection (Pinrich, 2000; Zimmermerman, 2002). Furthermore, Self-regulation is seen to be made up of cognitive, metacognitive and motivational components (Zimmerman, 2012). Performing the task involves cognitive strategies such as rehearsal, elaboration, and organization. The metacognitive component involves planning and reflection. The motivational component involves beliefs about own skills, such as self-efficacy (Ramdass and Zimmermerman, 2011). Sen (2006) writes that self-regulated students can regulate their time and study environments. Self-regulation capacity increases with age (Studenska, 2012). There are gender differences in the use of self-regulation which seem to vary with age and task. Research shows that, in learning, women generally report more intensive use of self-regulatory strategies than men. However, results of studies concerning relationships between gender and various self-regulation aspects are inconsistent (Studenska, 2012). The main driving force for self-regulation is metacognition which is discussed below.

Metacognition

Brown (1987), in a seminal review of metacognition, described metacognition in terms of knowledge and control (regulation) of one’s own cognitive system. Metacognition is seen as an important feature of cognitive theories. Children’s awareness of their own thoughts and their ability to evaluate them, act on them and modify them, are seen as critical for learning and cognitive development. Metacognitive knowledge is stable (declarative) knowledge about one’s cognitive system and, like any domain specific knowledge, increases with age. The regulation of the cognitive system is seen to be very important in bringing about development
and learning and Brown (1987) has traced the historical roots of the different meanings of metacognition as regulation as arising from cognitive development theories such as those of Piaget, Vygotsky’s and information processing models.

Information processing models stress the making of plans, monitoring actions and checking outcomes. Piaget’s cognitive development model seems to imply that these processes are implicit in younger children but come to conscious manipulation after formal operations are attained. It involves formulation and testing of theories. Vygotsky suggests a method for encouraging self-regulation though social interaction. In an adult–child interaction, first the adult acts as an overseer and gradually transfers executive control to the child.

**Self-regulation**

Self-regulation includes planning, awareness of understanding or performance and evaluation of both the processes and strategies of learning (Schraw et al, 2006). Planning is said to involve identification and selection of strategies and allocation of resources. It may include goal setting, activating relevant prior knowledge and budgeting of resources. It may also involve self-testing, paraphrasing, making links between the old and new knowledge and summarising. Evaluation involves appraising one’s learning and its products. It includes regulating the process of learning and revisiting and revising one’s goals. Metacognition and regulation develop spontaneously but can also be taught especially planning monitoring and evaluation (Salter, 2012).

Research shows that self-regulated students are more engaged in learning (Sen, 2006). They set their own goals and control the learning process by regulating time and the environment. They tend to keep their effort and attention even when faced with an uninteresting task. They pursue a positive environment as a result they perform better on tests than students who are not self-regulated. An instruction model called Plan, Organise, Monitor and Evaluate (POME) which aims to foster self-regulation, was used as a conceptual framework for this study.

**POME**

POME is an instructional model designed by Ley and Young (2001) that emphasizes self-regulation. It has four categories of activities namely: planning, organisation, monitoring and evaluation. In the planning category, students are expected to prepare the environment to concentrate and attend to the learning process. Whilst in the organisation category students are expected to organise the materials for studying. For monitoring students are expected to keep records, monitor and review tests. Lastly, in the evaluation category, students are expected to evaluate completed work, reread tests to prepare for further testing. Figure 2 shows the relationship between self-regulation and POME.
Although POME is an instructional programme, designed to foster the development of self-regulation in all subjects, in this study it was used as an assessment tool to explore if students could manifest self-regulation. Table 1 describes the POME activities as used in this study.

Table 1: POME activities used in the study

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Strategy examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare</td>
<td>Setting time for studying and timeline</td>
<td>setting time for studying</td>
</tr>
<tr>
<td></td>
<td>Finding suitable environment for studying</td>
<td>Setting timeline for studying a certain material.</td>
</tr>
<tr>
<td></td>
<td>Preparing for a class lesson</td>
<td>looking for a quiet place to study in e.g Library, ground or classroom</td>
</tr>
<tr>
<td></td>
<td>Preparing for a test</td>
<td>Reading just before a class lesson</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Revise material learnt/Practice answering test question</td>
</tr>
<tr>
<td>Organise</td>
<td>Organising resources/materials</td>
<td>Borrowing textbooks from library/friends</td>
</tr>
<tr>
<td></td>
<td>Organizing how to study and learn (strategies)</td>
<td>Taking short notes in class while the teacher is teaching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marking where one does not understand,</td>
</tr>
<tr>
<td></td>
<td>Organising what to study (content)</td>
<td>Listing the order of studying, identifying key points, choosing a topic to study</td>
</tr>
<tr>
<td>Monitor</td>
<td>Monitor progress</td>
<td>Checking objectives of topics after reading notes, answering end of topic questions,</td>
</tr>
<tr>
<td></td>
<td>Monitor performance</td>
<td>Keep a file/records of test results</td>
</tr>
<tr>
<td></td>
<td>Check understanding</td>
<td>Checking for the correct answers after completing an assignment, asking oneself questions about the material before beginning a class or study</td>
</tr>
</tbody>
</table>
Evaluate learning strategies
Identifying effective/ineffective learning strategies
Comparing textbooks
Comparing one’s score to the previous score.
Checking against Objectives
Comparing effort to learning/scores in a test

Method

The study used a survey design since the objectives were to describe how students use self-regulation to study biology and the relationship between self-regulation use and gender and the year of study. The survey findings were augmented with semi-structured interviews.

Population and Sample

The population was secondary school students in five boarding schools in Zomba administrative district. In Malawi the education system has eight years of primary education, four for secondary and four for a general degree. In the primary school learners are promoted to the next class on basis of passing teacher made examinations. Those who fail are allowed to repeat and this leads to a wide age range in the primary and subsequent classes. At the end of primary school learners take a national examination whose results are used for selection into secondary school. The transition rate from primary to secondary school is about 40%. There are four types of public secondary schools in Malawi: National schools which have the best students and resources, followed by District boarding and day schools, and lastly community day secondary schools. This study used four of the district boarding schools in the administrative district of Zomba. A sample of 50 year 9 and 50 year 11 students were randomly sampled from each school. The average enrolment is 150 students per year group. Two of the schools were single sex (one all boys and the other all girls). For the COED schools 50% of the sample was girls. The total sample was 400. Furthermore, four students from each school randomly selected from the sample to be interviewed making a total of 16 interviews.

Research Instruments

The study used a questionnaire and a semi structured interview schedule

The Questionnaire

A questionnaire was developed by the first author using POME categories. The questionnaire had three parts. The first part elicited students’ personal details. The second part of the questionnaire asked students to rate statements that were developed from POME categories described in Table 1. Each POME category had three statements describing examples of activities that could be done by students. The students were asked to rate the statements on a four-point Likert scale of “Always, Often, Sometimes and Never” The reliability of this part of the questionnaire was checked using test-retest method during a pilot study in the fifth boarding school. Three statements (one of monitoring category and two of evaluation category) were shown to be unreliable and were removed from the questionnaire. Due to lack of time,
they were not replaced. This reduced the confidence with which we can say something about the use of evaluation. The third part comprised two open ended questions which asked to describe what the students do to prepare for a test and to check their understanding.

**The interview guide**

Qualitative data were collected using a semi-structured interview guide which had five questions on POME categories. The questions asked how the students ensure that they do all the things they want to do, how they choose the materials they use to study, how they check if their performance is improving and how they identify their strengths and weaknesses. Follow up questions, which arose from the students’ responses, probed for more information. The interview guide was tried out in the pilot schools. This was done by interviewing two students from the school and the questions were revised accordingly.

**Data collection**

Data was collected by the first author. Although 400 questionnaires were given out, only 385 were used as others were not complete. The face-to-face interviews on average lasted 30 minutes.

**Data analysis**

In quantitative analysis, descriptive statistics, mostly frequencies, were calculated for each item of the questionnaire using the excel software. A chi-squared test was used to test significance of differences at or below the 95% confidence level (p<0.05). In qualitative analysis, the responses to the open-ended questions in the questionnaire and the interviews for each participant were read and themes developed which were used to code the data.

**Findings**

Research questions have been used to structure the reporting of findings.

**What strategies of self-regulation do students use as they learn biology?**

In answering the first question frequencies of how the students rated the POME activities were worked out. The Likert scale was collapsed to yes and no for the sake of simplicity. “Always and Often” were taken as yes, whilst “Sometimes and Never” as no. Table 2 gives the frequencies of how the students rated the self-regulation activities used in learning in biology.

**Table 2:** Perception of year 9 and year 11 students’ use of self-regulation in biology

<table>
<thead>
<tr>
<th>Strategy</th>
<th>% of learners</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Planning strategies</strong></td>
<td></td>
</tr>
<tr>
<td>Study previous lesson notes</td>
<td>48</td>
</tr>
<tr>
<td>Make study time table</td>
<td>87</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>78</td>
</tr>
<tr>
<td><strong>Organization strategies</strong></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>64</td>
</tr>
<tr>
<td>Mark difficult places when studying</td>
<td>55</td>
</tr>
</tbody>
</table>
Planning for lessons and examinations

In this category most students have a timetable (87%) and study past papers (78%) but few read notes from the previous lesson (48%) to prepare for the next lesson. This was corroborated by students interviewed who said they have a timetable or a do list for each day. However, students in responding to open ended questions of the questionnaire mentioned that they prepare for tests through group discussions, revisiting their class exercises, borrowing different books from friends or library, revising all the notes a day before the test, consulting their teacher or their friends for clarification of some concepts and study past papers.

Organisation

Most students indicate that they write short notes (78%) and move to a quiet place (64%) as activities that facilitate organisation. In addition, students mentioned during interviews that they are able to organize their learning materials by borrowing text books from the library.

Monitoring work

Generally, it appears that many students monitor their work by having a file where they keep their test papers (85%). This file helps them to check their progress by comparing the previous and present scores. However, few students go back to their notes to check for the correct answer (55%) when they are not sure about the answer to an assignment question. During interviews most students mentioned that they compare their test scores for the previous term and the test scores for the current term. Furthermore, learners are also able to monitor the materials they use. For example, when asked how they select the biology books some responded as follows;

Student 1: “I take 2 to 3 books and compare the way authors write the information. Then I go for the book which is well explained so that I can understand the information”

Student 2: “our teacher gives us the syllabus. So, I choose a book that is in accordance with the syllabus”

Evaluation

In this category, it appears that most of the students are able to evaluate their learning through identifying useful methods of studying (70%). Table 3 gives the responses to the statement “list all the activities you do to make sure that you have understood the content you were studying”. 
Table 3: Frequency of the strategies used in self-evaluation

<table>
<thead>
<tr>
<th>Activity</th>
<th>N= 385</th>
<th>% of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask myself questions</td>
<td>243</td>
<td>63</td>
</tr>
<tr>
<td>Friend asks questions</td>
<td>86</td>
<td>22</td>
</tr>
<tr>
<td>Summarise Information after studying</td>
<td>49</td>
<td>13</td>
</tr>
<tr>
<td>Make short notes while studying</td>
<td>42</td>
<td>11</td>
</tr>
<tr>
<td>Self-testing</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Answer past papers</td>
<td>19</td>
<td>5</td>
</tr>
</tbody>
</table>

What differences are there in the use of self-regulation between boys and girls?

The second question sought to find out if there was any difference between boys and girls in their use of self-regulation. The findings are desegregated by year of study, starting with year 9 and followed by year 11. Table 4 shows differences in students’ use of self-regulation strategies in school biology between year 9 boys and girls.

Table 4: Self-regulation strategies reported by year 9 boys and girls

<table>
<thead>
<tr>
<th>Strategy</th>
<th>% of year 9 girls</th>
<th>% of year boys</th>
<th>P-values of chi-square test</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A O S N</td>
<td>A O S N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous lesson notes</td>
<td>32 29 37 2</td>
<td>36 20 39 5</td>
<td>0.0608</td>
<td>NS</td>
</tr>
<tr>
<td>Make study time table</td>
<td>74 15 8 2</td>
<td>62 18 12 3</td>
<td>0.401</td>
<td>NS</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>61 19 19 1</td>
<td>59 13 28 0</td>
<td>0.126</td>
<td>NS</td>
</tr>
<tr>
<td>Organising strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>40 21 35 4</td>
<td>55 13 25 7</td>
<td>0.00541</td>
<td>S</td>
</tr>
<tr>
<td>Mark points when studying</td>
<td>31 23 40 6</td>
<td>38 21 28 13</td>
<td>0.0168</td>
<td>S</td>
</tr>
<tr>
<td>Write short notes</td>
<td>82 9 8 0</td>
<td>55 15 27 3</td>
<td>0.000</td>
<td>S</td>
</tr>
<tr>
<td>Monitoring strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check correct answer</td>
<td>40 11 25 24</td>
<td>30 14 22 34</td>
<td>0.0579</td>
<td>NS</td>
</tr>
<tr>
<td>File test papers</td>
<td>81 11 8 0</td>
<td>75 7 11 7</td>
<td>0.0300</td>
<td>S</td>
</tr>
<tr>
<td>Evaluating strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify useful methods</td>
<td>43 20 34 3</td>
<td>43 24 28 5</td>
<td>0.339</td>
<td>NS</td>
</tr>
</tbody>
</table>

Key: A=Always, O=Often, S=Sometimes, N=Never

Key: S=significant (p-values < 0.05), NS=Not Significant (p-values ≥ 0.05)
There are no significant differences between year 9 girls and boys in planning and evaluation categories and significant differences in the organisation categories. As for monitoring, there is significant difference in filing past papers and none in checking for the correct answer.

Table 5 shows differences in students’ use of self-regulation strategies in school biology between year 11 boys and girls.

**Table 5: Year 11 boys and girls reported use of self-regulation strategies**

<table>
<thead>
<tr>
<th>Strategy</th>
<th>% of form 3 girls</th>
<th>% of form 3 boys</th>
<th>P-values of chi-square test</th>
<th>significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>O</td>
<td>S</td>
<td>N</td>
</tr>
<tr>
<td>Planning strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous lesson notes</td>
<td>12</td>
<td>20</td>
<td>59</td>
<td>9</td>
</tr>
<tr>
<td>Make study time table</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Go through past papers</td>
<td>63</td>
<td>17</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Organising strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>31</td>
<td>20</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>Mark points when studying</td>
<td>28</td>
<td>23</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>Write short notes</td>
<td>51</td>
<td>25</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Monitoring strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check correct answer</td>
<td>46</td>
<td>14</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>File test papers</td>
<td>73</td>
<td>12</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Evaluating strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify useful methods</td>
<td>43</td>
<td>32</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Key: A=Always, O= Often, S=Sometimes, N=Never

Key: S=significant (p-values < 0.05), NS= Not Significant (p-values ≥ 0.05)

There is significant difference between year 11 girls and boys in all categories except for checking for the correct answer.

Table 6 gives a summary of the difference between boys and girls, focusing on the direction of the differences.
Table 6: The difference between self-regulation activities used by girls and boys in learning biology

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Year 9 girls vs Year 9 boys</th>
<th>Year 11 girls vs year 11 boys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous lesson notes</td>
<td>Not significant</td>
<td>More boys do not use</td>
</tr>
<tr>
<td>Make study time table</td>
<td>Not significant</td>
<td>More girls</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>Not significant</td>
<td>More girls</td>
</tr>
<tr>
<td>Organization category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>More boys</td>
<td>More boys</td>
</tr>
<tr>
<td>Mark difficult places when</td>
<td>More boys</td>
<td>More boys</td>
</tr>
<tr>
<td>studying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write short notes</td>
<td>More girls</td>
<td>More girls</td>
</tr>
<tr>
<td>Monitoring category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check for correct answer</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>File test papers</td>
<td>More girls</td>
<td>More girls</td>
</tr>
<tr>
<td>Evaluating category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify useful methods</td>
<td>Not significant</td>
<td>More boys</td>
</tr>
</tbody>
</table>

Five out of nine items show no significant differences between boys and girls in year 9. On the other hand, there are significant differences in 8 out of 9 items in year 11. It is thus seen that, generally, there are less differences between year 9 girls and boys than differences between year 11 girls and boys in almost all the categories. It would seem that more year 11 girls make study timetable, file and go through past papers than year 11 boys. On the other hand, more year 11 boys move to a quiet place, mark difficult places in textbook and identify useful methods than year 11 girls. There is need to explore factors that contribute to this differential development.

What differences are there in the use self-regulation between students in different years?

The third question aimed at finding out if there were differences between the year 9 and year 11 students. The comparisons were made separately for girls and boys. Table 7 shows differences in students’ use of learning strategies in school biology between year 9 boys and year 11 boys.

Table 7: The reported use of learning strategies for year 9 and year 11 boys

<table>
<thead>
<tr>
<th>Strategy</th>
<th>% of year 9 boys</th>
<th>% of year 11 boys</th>
<th>P-values of chi-square value</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous notes</td>
<td>36 20 39 5</td>
<td>26 19 53 3</td>
<td>0.0302</td>
<td>S</td>
</tr>
<tr>
<td>Make study time table</td>
<td>62 18 12 3</td>
<td>78 6 14 3</td>
<td>0.0000</td>
<td>S</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>59 13 28 0</td>
<td>51 29 20 0</td>
<td>0.00406</td>
<td>S</td>
</tr>
<tr>
<td>Organization strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>55 13 25 7</td>
<td>55 21 19 5</td>
<td>0.125</td>
<td>NS</td>
</tr>
</tbody>
</table>
There are significant differences between year 9 boys and year 11 boys in all planning category activities and no significant difference in all the organisation category. There is significant difference in the monitoring category of checking for the correct answer but none for filing past papers. There is significant difference in the evaluation category.

Table 8 shows differences in students’ use of self-regulation strategies in learning biology between year 9 girls and year 11 girls.

Table 8: The reported use of Self-regulation strategies for year 9 and year 11 girls

<table>
<thead>
<tr>
<th>Strategy</th>
<th>% of year 9 girls</th>
<th>% of year 11 girls</th>
<th>P-values of chi-square test</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>O</td>
<td>S</td>
<td>N</td>
</tr>
<tr>
<td>Planning strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous notes</td>
<td>32</td>
<td>29</td>
<td>37</td>
<td>2</td>
</tr>
<tr>
<td>Make a study time table</td>
<td>74</td>
<td>15</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>61</td>
<td>19</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Organizing strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>40</td>
<td>21</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>Mark points when studying</td>
<td>31</td>
<td>23</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>Write short notes</td>
<td>82</td>
<td>9</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Monitoring strategies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check correct answer</td>
<td>40</td>
<td>11</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>File test papers</td>
<td>81</td>
<td>11</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Organizing strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify useful methods</td>
<td>43</td>
<td>20</td>
<td>34</td>
<td>3</td>
</tr>
</tbody>
</table>

Key: A=Always, O= Often, S=Sometimes, N=Never

Key: Significant (p-values < 0.05), NS= Not Significant (p-values ≥ 0.05)
there is no significant difference in all the categories, except in study previous notes. There is no significant difference in the evaluation category.

Table 9: The difference between self-regulation activities used by year 9 and year 11 students

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Year 9 girls vs year 11 girls</th>
<th>Year 9 boys vs year 11 boys</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planning category</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study previous lesson notes</td>
<td>More form 1 girls</td>
<td>More form 1 boys</td>
</tr>
<tr>
<td>Make study time table</td>
<td>Not significant</td>
<td>More form 3 boys</td>
</tr>
<tr>
<td>Go through past papers</td>
<td>Not significant</td>
<td>More form 1 boys</td>
</tr>
<tr>
<td><strong>Organization category</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Move to a quiet place</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>Mark difficult places when</td>
<td>More form 1 girls</td>
<td>Not significant</td>
</tr>
<tr>
<td>studying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write short notes</td>
<td>More form 1 girls</td>
<td>Not significant</td>
</tr>
<tr>
<td><strong>Monitoring category</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check for correct answer</td>
<td>More form 3 girls</td>
<td>More form 3 boys</td>
</tr>
<tr>
<td>File test papers</td>
<td>More form 1 girls</td>
<td>Not significant</td>
</tr>
<tr>
<td><strong>Evaluating category</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identify useful methods</td>
<td>Not significant</td>
<td>More form 3 boys</td>
</tr>
</tbody>
</table>

In general there were significant differences in some categories between year 9 and year 11 students in the planning category, both year 9 boys and year 9 girls surpassed year 11 boys and year 11 girls in studying previous lesson notes respectively. On the other hand, year 11 boys surpass year 9 boys in making a study time table whilst more year 9 boys than year 11 boys’ study past papers.

In the organising category, the findings have revealed that there are more year 9 girls using the strategies that facilitate organization as compared to the year 11 girls. There were no significant differences between the boys.

In the monitoring category, it appears that there are some strategies where year 9 students surpass year 11 students. There were more year 11 students than year 9 students who said they checked for the correct answer when they are not sure about the answer to an assignment question, while more year 9 girls than year 11 girls keep their test papers in a file. Both of these strategies facilitate monitoring. The qualitative study results also showed that more year 9 students check for the correct answers than the year 11 students. This was evidenced through the results of the interviews reported when students were asked to mention what they do when they see that they have failed an exercise or a test, almost all the year 9 students unlike year 11 students mentioned ‘consulting a teacher or a friend who has done well’ as strategies they use in checking for the correct answer.

In the evaluation category, the study has found out that the year 11 boys surpass year 9 boys in identifying useful methods of studying. There is no significant difference between year 11 girls and the year 9 girls in the evaluation category.
Discussion of the findings

The findings show that the activities in POME that were frequently reported (80% and above) were making a study timetable, filing and going through past papers and writing notes. Save for the time table and the notes it seems use of past papers dominated. This may be symptomatic of a curriculum that is dominated by national examinations. It would seem that students are not focussing on understanding but on performance. Self-regulation can be inhibited by focus on examination. Similarly, Ngwira (2011) found that most students in secondary schools in Malawi employ rehearsal strategies that reinforce simple memory rather than critical thinking or mastery of concepts. Indeed, in Malawi the school curriculum is dominated by examinations. There are national examinations at every transition point; from primary school to secondary school and at the end of secondary school. Self-regulated students strive in environments that are more cooperative and less competitive and students are independent and aim at mastery learning. However, in Malawi because of inadequate provision of education opportunities both at secondary and tertiary levels there is a lot of competition in secondary schools. It is known that schools that have good performance drill the examination. These situations may inhibit the development of self-regulation skills that POME tapped in this study.

It could also be that the use of timetable and writing notes are common because they are taught in school. The schools have several time tables: school, prep and extra curriculum. The students may model from this to make their own. As for writing notes, much of teaching involves copying notes or making their own notes (Mbano, 2015). Since students take notes in class often, no wonder that this strategy seems to be well developed. During interviews some students mentioned summarising information from reading or writing notes as ways of checking/evaluating understanding.

The category with the least frequency is “the study of previous notes in preparation for the next lesson” (48%). This is in agreement with the observation that the students’ study to prepare for examinations rather than understanding.

In terms of POME, students reported good use of planning, organisation and monitoring. However, evaluation was lower. This may indicate a lack of reflection. It may not be so surprising in a class where didactic teaching is practiced, as is the case in Malawi, as students focus on acquisition of content rather than the learning process.

On gender difference it was found that there were no significant differences between boys and girls in year 9 in their report on use of planning, but in year 11 girls had significant higher frequencies than boys. This is opposite to Ngwira’s (2011) finding where more boys than girls reported that they use time management strategies such as using a study timetable and setting up study goals. In the organisation category both year 9 and year 11 boys had significantly higher frequencies than year 9 and year 11 girls respectively. More Year 11 girls said they file past papers as a way of monitoring performance whilst more year 11 boys said they identified the best method as an evaluation strategy. This concurs with Ngwira’s (2011) findings which says that there were more boys than girls who reported that they use evaluation strategies such as answering end of topic questions and past paper questions when studying. On the other hand
Studenska (2012) says women report more intensive use of self-regulation strategies than men. In addition, the strategies of plan, organise, implement, reflect and change are less difficult for women than for men. Overall, there is less gender difference in year 9 than in year 11. This suggests that there is differential development which may be as a result of different experiences in the school. There are many factors that may contribute to this, such as competition in classes already mentioned above. Competition does not foster the development of Self-regulation (Salter, 2012) Teachers are encouraged to “reward and recognise effort and self-improvement as opposed to performance or ability, provide students with opportunities to experience personal improvement, use a variety of evaluation methods, and reduce emphasis on social competitions and comparisons of students’ work” (Salter, 2012 p2).

Girls and boys react different to competition, with boys striving and girls shying away.

On whether the year affected the frequencies, it was found that in year 9 girls wrote notes, referred to previous notes and marked difficult places more often than year 11 girls. On the other hand, year 11 girls checked for the correct answer more than year 9 girls. Studies elsewhere have shown that planning, organising and implementation learning is less difficult for primary school students than for upper secondary students (Studenska, 2012). It seems the higher the level of education the more complex self-regulation of the tasks faced by the students (Studenska (2012), Mei-ling (2009), Vukman and Licardo, (2010)). For boys it was found that more year 9 boys reported using previous notes and past papers than year 11 boys. On the other hand, more year 11 boys reported making a time table, checking for the correct answer and identifying the best method than year 9 boys. Thus, it seems year 9 boys are good in planning whilst year 11 boys are good in monitoring and evaluation. This somehow shows some form of development in that at year 11 they are monitoring and evaluating their work. Overall, it would seem that at school level there is limited guidance on how to use self-regulation, as generally year 9 and year 11 students are not much different. POME is an example of such an embedded instructional programme aiming at developing self-regulation which has shown positive results at post-secondary level.

**Conclusion**

The study showed that students in secondary schools use self-regulation in a variety of ways in biology lessons. In general findings of the study show that students plan, organise and monitor their learning but do not evaluate their work except for year 11 boys. There were some gender differences which were more prominent in year 11 than in year 9. The study points to more areas for further study such as to whether teachers address self-regulation in their teaching and examination of factors in the classroom that may facilitate the development of self-regulation.

**Reference**


THE VALUE OF INTEGRATING THE UN SUSTAINABLE DEVELOPMENT GOALS WITH A MICROSCALE EXPERIMENT FOR CHEMISTRY STUDENTS

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Abstract

The United Nation’s sustainable development goals (UN SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. Microscale chemistry kits already comply with many of the UN SDGs as they are greener, safer and more cost effective than traditional large-scale laboratory experiments. This qualitative study explored the value added for first-year chemistry students when the UN SDGs were integrated in a microscale experiment on industrial pollution: students were able to identify and explain relevant UN SDGs and communicate chemistry in context. Many students showed retention of the relevant UN SDGs two months after completing the experiment despite having no prior exposure to the UN SDGs. The majority of students felt that their laboratory experience was enriched by the inclusion of the UN SDGs, wished to learn more about the UN SDGs, and endorsed their inclusion as a graduate attribute.

Keywords: South Africa; chemistry; sustainable development; UN SDGs; microscale

Introduction

This study sought to fortify the curriculum of an extended first-year university chemistry course through the introduction of the United Nation’s Sustainable Development Goals (UN SDGs). The motivation of this study was to expand the laboratory experience of first-year students through laying foundations in sustainable development that will guide these young professionals as they prepare to make a difference in a world under-going the fourth industrial revolution. The motivation of this study is shared by many other international chemistry initiatives which aim to cultivate ethical professionals and informed global citizens through the integration of the UN SDGs in their curricula (Mahaffy, et al., 2017; O’Flaherty & Liddy, 2018). In fact, the preparedness of students to meet and explore the UN SDGs has risen to a highly desired graduate attribute in many tertiary institutions (Windsor, et al., 2014), including the tertiary setting for this study.

In this study, a microscale chemistry experiment was used to embed the UN SDGs into the curriculum. The focus of this study was to “nudge” student thinking about the UN SDGs by positioning chemistry concepts in the context of an experiment that simulates industrial pollution. The decision to integrate the UN SDGs had further advantages for students in that exploring chemistry in context is known to provide opportunities for meaningful learning in the laboratory (De Jong & Taber, 2014) and may even improve student attitudes and motivations (Bennett, et al., 2007; Petillion, et al., 2019).
Literature Review

Chemistry’s interest in sustainability and green alternatives began in the early 1990s (Anastas & Warner, 1998). This was due to the view that although chemistry has provided much for the advancement of humanity, chemistry has also made large contributions to global problems such as pollution and climate change (Matlin, et al., 2016). Global interests in sustainability also grew in this time, and in 2015 the United Nations General Assembly proposed seventeen international sustainable development goals for 2030 (see Figure 1). The UN SDGs are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. In the same year, there was a commitment from the International Union of Pure and Applied Chemistry (IUPAC) to aid in the attainability and sustainability of these goals. Since then, many international chemistry curricula have been developed to focus on green chemistry and sustainable education (Mammino, et al., 2015; O’Flaherty & Liddy, 2018).

![Figure 1](https://sustainabledevelopment.un.org/)

Furthermore, chemistry education has invested heavily in ‘chemistry in context’ and ‘systems thinking’ approaches in the classroom and laboratory to support sustainable development (Bradley, 2019; Mahaffy, et al., 2017; Ogino, 2019; Orgill, et al., 2019). Systems thinking in chemistry education (STICE) is more complex than chemistry in context as it involves exploring the effects of the interface of chemistry with other systems like “the biosphere, the environment, human and animal health” (Matlin, et al., 2016) along with the flow of molecules throughout system-oriented concept map extensions (Mahaffy, et al., 2019). Chemistry in context implies chemistry learning opportunities embedded in rich contexts that develop preliminary systems thinking (Mahaffy, et al., 2017).

As the importance of sustainable development gained global traction, many tertiary institutions have focused on sustainability development as one of their graduate attributes. This has led to the active inclusion of the UN SDGs into many tertiary chemistry curricula (Windsor, et al., 2014), whereas prior to this the focus was more general, including chemists’ professional and environmental ethics (Brown & Wylie, 2006; Tafesse & Mphahlele, 2018).

However, gauging students’ understanding of ‘chemistry in context’, that is, the complex systems with which chemistry interfaces, is no small feat (Talanquer, 2019), nor is gauging the
students’ uptake of graduate attributes (Kensington-Miller, et al., 2018). For this reason, the SEEN framework proposed by Kensington-Miller et al. (2018) was used to loosely scaffold the integration of the UN SDGs graduate attributes into the first-year chemistry course:

*Specify:* The graduate attribute of sustainable development was targeted. Students were made aware that they should identify relevant UN SDGs

*Explain:* Students were asked to explain their understanding of relevant UN SDGs

*Embed:* The UN SDGs were embedded into a particular learning activity – a microscale chemistry experiment

*Nudge:* Students’ thinking around the UN SDGs was broadened to beyond the laboratory environment through the context of the experiment – industrial pollution

There are many existing motivations for using microscale science experiments in chemistry laboratories, as they require less reactants and produce less waste, are safer, and are more cost effective (Mayo, et al., 1994; Singh, et al., 2000). Microscale chemistry kits emerged in South Africa in the early 1990’s and in 1996 these were keystone in the UNESCO Global Microscience Programme at school level. At the turn of the twenty-first century, IUPAC encouraged microscale experiments at the tertiary level (Bradley, 2001).

The researcher proposed a framework, in that microscale chemistry experiments have dual potential in terms of the UN SDGs (see Figure 2). It is clear that the use of microscale chemistry experiments supports the UN SDGs given their green nature (low health risks and low environmental impacts) but microscale experiments may also act as vehicles for the discovery and discussion of the UN SDGs themselves (see green arrow in Figure 2). Such a symbiotic relationship creates a space for teaching and learning of chemistry in context.

![Figure 2](image_url) Framework showing the linkages between the UN SDGs and microscale chemistry.

**Research Questions**

Three research questions were developed to interrogate the value, for students, of integrating the UN SDGs within a microscale lab experiment on pollution. The study sought to add value to the students’ laboratory experience by exposing students to the UN SDGs during a real-life laboratory experiment that touches on issues of concern for young scientists and ethical citizens.
1. To what extent were students able to motivate for UN SDGS relevant to the microscale experiment?

2. How does the extent of exposure to the UN SDGs prior to the microscale experiment compare with the student retention of the UN SDGs after the experiment?

3. What are students’ reflections on the value of integrating the UN SDGs with the microscale experiment?

**Background**

General chemistry is a core module in the extended programme for BSc Biological and Physical Sciences degrees. During this study, 433 students were enrolled in general chemistry. The student population was diverse in terms of gender, race, language and socio-economic background. To fulfill the requirements of the general chemistry module, all students were required to complete six laboratory experiments per semester. Each experiment was approximately three hours long and the majority of the experiments were microscale. Five laboratory sessions were scheduled per week to accommodate the large student numbers. Students usually completed the experiment individually and handed in a written report sheet at the end of each experiment. Students were expected to prepare for each experiment; this included readings from the textbook, watching video links, and conducting independent research. Students were assisted in the laboratory by senior students in the role of laboratory demonstrators. A week prior to each experiment, the demonstrators were trained in relevant chemistry concepts, as well as health and safety.

**Experiment**

An existing microscale experiment was chosen for this study. The experiment was entitled “Simulation of industrial pollution” and was based upon the RADMASTE Practical Water Quality Testing microscale experiment. The aims of the experiment were to look at the production of pollution emissions and the effectiveness of two measures to limit air pollution and subsequent water pollution. Students formed very small (and thus harmless) quantities of sulphur trioxide gas using their microscale apparatus and micro-quantities of reagents, according to the reactions given below:

\[
\text{Na}_2\text{SO}_3 (s) + 2 \text{HCl (aq)} \rightarrow \text{SO}_2 (g) + \text{H}_2\text{O (l)} + 2 \text{NaCl (aq)}
\]

\[
\text{SO}_2 (g) + \text{atmospheric oxygen} \rightarrow \text{SO}_3 (g)
\]

When the sulphur trioxide gas reacted with water, the acidity of the water increased, as sulphuric acid was formed. This acidification was clearly visible to students as the universal indicator in the water alongside the “factory” changed from green (neutral) to red (acidic). Students attempted two measures to reduce the water acidification: firstly repeating the reaction and attaching a chimney to the “factory” to elevate the emissions into the “atmosphere” (see Fig. 3). Secondly, students repeated the reaction again, this time packing the chimney with CaO, also known as quick lime, to simulate industrial flue-gas desulfurization (see Fig. 3).
This experiment was chosen as it already had implicit value for the discussion and discovery of the UN SDGs. The question, “Identify and explain the UN SDGs highlighted during this experiment”, was added to the students’ report sheets to support students in making their own explicit links between the microscale experiment and the UN SDGs. Students were required to do their own research on the UN SDGs prior to the experiment.

**Methodology and analysis**

This was a small-scale qualitative study to explore the richness of the value of integrating the UN SDGs for first-year students. Two different data collection methods were used. Opportunistic data (in the form of the students report sheets) was collected to answer Research Question 1. Student answers to an online student questionnaire were collected in an attempt to answer Research Questions 2 and 3. Ethical clearance was obtained for this study, NAS088.

The collection of the opportunistic data was conducted before the graded report sheets were handed back to the students. Five report sheets were selected at random from each of the five laboratory sessions in that week ($n = 25$), these were photocopied for analysis. Only 25 report sheets were collected due to the limited man-power of a single researcher.

The analysis did not focus on the entire report sheet, but focused on the students’ answers to the first question, “Identify and explain the UN SDGs highlighted during this experiment”. The seventeen UN SDGs were used to deductively code the text. The coding was cross-checked by the laboratory manager. Along with identifying the UN SDGs that students felt were relevant, representative excerpts were selected for each of the identified UN SDGs. The quality of the students’ answers was also assessed for evidence of thinking about ‘chemistry in context’.

The student questionnaire took the form of a voluntary online Qualtrics survey. The survey was implemented two months after students completed the experiment, this time lapse was deliberate as student retention of the UN SDGs was of interest as well as providing students with enough time for reflection on the value of the integration of the UN SDGs with the microscale experiment. During this two-month period, students completed the first semester and their mid-year exam cycle. Limited student participation in the questionnaire ($n = 52$) could be accounted for by its voluntary nature and, possibly, its timing at the end of the exam period.
The online survey was designed to explore research questions two and three with a blend of open and closed items (see Figure 4). Survey questions Q2 and Q4 only appeared based on the student’s choices for survey Q1 and Q3 respectively.

<table>
<thead>
<tr>
<th>Question</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 – Remember Prac 5: Simulation of industrial pollution. You were asked to “Identify and explain the UN sustainable development goals (SDGs) highlighted during this experiment”. Was this the first time you had been exposed to the UN SDGs?</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td></td>
</tr>
<tr>
<td>• No</td>
<td></td>
</tr>
<tr>
<td>Q2 - Before this experiment, how were you exposed to the UN SDGs?</td>
<td></td>
</tr>
<tr>
<td>Q3 - From memory, do you recall any of the UN SDGs that were highlighted in the Simulation of industrial pollution prac?</td>
<td></td>
</tr>
<tr>
<td>• Yes</td>
<td></td>
</tr>
<tr>
<td>• No</td>
<td></td>
</tr>
<tr>
<td>Q4 - Which UN SDGs were highlighted in the Simulation of Industrial Pollution prac? Please answer in your own words from your own memory, don’t Google!</td>
<td></td>
</tr>
<tr>
<td>Q5 - To what extent do you agree with the following statements?</td>
<td></td>
</tr>
<tr>
<td>• I would like to learn more about the UN SDGs</td>
<td></td>
</tr>
<tr>
<td>• Doing a lab experiment which included the UN SDGs made it more meaningful for me</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. Qualtrics survey designed for this study entitled “Industrial Pollution and UN SDGs”

Findings

Report sheets were numbered randomly (e.g. RS1-RS25) to ensure the anonymity of the students. In total, nine of the seventeen UN SDGs were identified by students as relevant to the experiment. The findings from the analysis of the students’ report sheets revealed that many of the students motivated for two or more UN SDGs that they felt were relevant to the laboratory experiment on industrial pollution. The quality of these motivations was high, showing links to systems beyond the isolated chemical one that students were exploring in the laboratory (see Table 1).

Table 1. Identified UN SDGs and representative supportive reasoning

<table>
<thead>
<tr>
<th>UN SDG</th>
<th>Representative Excerpts(s) from report sheets</th>
<th>Frequency (n)</th>
<th>Percent of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 Life below water</td>
<td>“amphibians and fish will die due to this pollution” RS3 “acid rain will cause ocean acidification leading to the loss of coral reefs and the lives of many marine organisms” RS17</td>
<td>13</td>
<td>25%</td>
</tr>
<tr>
<td>13 Climate action</td>
<td>“Climate change is increasing due to greenhouse gases… all countries agreed to work to prevent a global temperature increase” RS18</td>
<td>12</td>
<td>23%</td>
</tr>
</tbody>
</table>
“Some pollutants perpetuate the problem of global warming, so extra care has to be taken by manufactures to reduce CO$_2$ and SO$_2$ footprints” RS13

“Acid rain water will leach aluminium from soil and then flow into streams and lakes” RS2
“Acid rain which pollutes streams, lakes and other water sources by dropping the pH to below critical levels” RS24
“This experiment looks at the neutralisation of acid gases…to stop acid rain, which pollutes bodies of water” RS21

“a properly built factory would produce reduced pollution and would be better for everyone” RS8

“people should try using public transport to reduce the emission of unwanted gases” RS11

“Life of animals on land will be in danger as they depend on water that is not polluted, they will die also” RS3
“Acid rain will decrease the growth of plants” RS2

“air pollution like SO$_2$ & NO$_2$ can cause respiratory diseases like chronic asthma, as it makes it hard for people to breathe” RS2

“Focus should be placed on finding clean alternatives to fossil fuels used in industrial processes” RS13

“manufacturers need to place more emphasis on using resources wisely and in such a way that the health and well-being of the locals is not compromised” RS13

When evaluating the students’ responses, all UN SDGs were permissible (as long as the student motivation, i.e. the links to the industrial pollution context, were explained adequately). In the sciences, there is often a wrong and a right answer, however, when viewing chemistry in context, the intricacies of the relationships and networks encourage a variety of interpretations.

**SDG 13 Climate Action, SDG 14 Life below water and SDG 6 Clean water and sanitation** were the most frequently identified by students. The latter two findings were expected by the researcher as they represent direct impacts of air to water pollution. However, the identification of climate action (which can largely be described by climate change) as a highly relevant SDG was a finding that may suggest consequential and integrated thinking, indicative of the goals of ‘chemistry in context’. It was also likely that the topical nature of climate change and global warming contributed to the maturity of students’ contextual considerations and awareness.
As educators, one hopes for lasting effects beyond the confines of the classroom or laboratory. The responses to survey Q3 and subsequent Q4, showed that more than half of the students (29 of 52) recalled relevant UN SDGs after a period of two months. All 29 students were able to successfully discuss the relevant UN SDGs in their own words, for example, “Ensure there is enough clean drinking water for everyone and to ensure it is used efficiently and looked after for future generations”.

The retention of the UN SDGs suggests true meaningful learning, especially in light of the fact that >60% of the survey respondents indicated that they had had no prior exposure to the UN SDGs before encountering them in the experiment. Of respondents who had indicated that they had prior experience with the UN SDGs, 12 respondents indicated the UN SDGs were included at high school level and 5 respondents indicated that their awareness stemmed from social media and news.

In Q6 of the online survey, students were asked to reflect on the individual value of merger of the UN SDGs with the industrial pollution microscale experiment. Two primary codes emerged from the data (see Table 2). ‘Chemical Concepts’ was the first code that emerged and corresponded to key chemical ideas relating to the experiment: the application of acid-base gas-forming reactions, understanding limiting measures on reactions, and, the use of indicators to visualise pollution. Student’s valued their chemical understanding, but more so, they were appreciative of the complexities around the chemistry system that they were able to explore, from this a second code emerged, ‘Chemistry in context’. It was clear that students found the experiment worthwhile and interesting, “I valued it so much, I did not know much about the UN SDGs, so it helped me to understand and want to know more about it”.

Table 2. Coding of student responses to the personal value of the experiment

<table>
<thead>
<tr>
<th>Code</th>
<th>Representative Quote(s) from Students</th>
<th>Frequency (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical Concepts</strong></td>
<td>Students simulating pollution through appropriate reactions and learning about limiting measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“To observe substances that cause pollution”</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>“Learning how to implement effective methods to prevent water pollution”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“It provided me with a better understanding as to how pollution works and its effects, even on such a small scale.”</td>
<td></td>
</tr>
<tr>
<td><strong>Chemistry in context</strong></td>
<td>Students appreciating the interface of chemistry with other systems. Chemical systems are not examined in isolation, the far reaching effects of chemical phenomena are acknowledged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“One the reactions corroded my combo plate, so it really opened my eyes to the extent of the damage these pollutants cause for our planet”</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>“It opened my eyes to how the world is at the current moment and the impact one individual can make to the environment”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“it helped me remember that we need to take care of the world”</td>
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</tbody>
</table>

Further probing the value of the integration of the UN SDGs with the microscale experiment revealed that 73% of the respondents either agreed or strongly agreed that the merger of the UN SDGs with the laboratory experiment made it more meaningful for them (see orange in Figure 5). Students were responding to statements on a 5 point Likert scale (see Q5, Figure 5).
The other two statements in survey Q5 assessed students’ desire to know more about the UN SDGs (see blue in Figure 5) and their opinion on the inclusion of the UN SDGs as graduate attributes (see green in Figure 5). Again, the majority of respondents concurred with the statements given. Additionally, students were given an opportunity to comment or put forward their own questions at the end of the survey. Several students asked questions such as, “What is the university doing to achieve or integrate with these sustainable development goals?” or asked whether there were organisations that students could join to reach these goals.

![Figure 5. Likert scale responses to Q5 from the Qualtrics survey](image)

**Discussion**

Petillion et al. (2019) introduced preliminary systems thinking in introductory chemistry modules using the UN SDGs as a thematic or anchoring framework. Instead, in this paper, students were prompted to map relevant UN SDGs onto a microchemistry experiment on industrial pollution according to the SEEN framework. The first research question queried the extent to which first-year students would be able to identify and explain the UN SDGs relevant to the microscale experiment. From the analysis of the students’ report sheets it was clear that students were able to identify a wide selection of UN SDGs and motivate their relevance to the experiment appropriately.

Even though this study was small and qualitative in nature, similar findings to Petillion et al. (2019) emerged in terms of students thinking beyond the isolated chemistry system to seeing chemistry in context i.e. in relation to the systems around it. Specifically, evidence of thinking about chemistry in context may be in the students’ overarching concern for climate change as a result of chemical, industrial and environmental system interactions.

In attempting to answer the second research question, the self-reported exposure of first-year chemistry students to the UN SDGs prior to the microscale experiment was poor. This was an unanticipated finding as the UN SDGs were proposed in 2015, after a global ‘Decade of
Education for Sustainable Development’. Additionally, a large scale CAPS document analysis by Tsakeni (2018) revealed many opportunities for the inclusion of sustainable development education in physical sciences in South African schooling. A possible reason for this disjunction may be that learners are exposed unknowingly at school level, without the links from their curriculum to the UN SDGs being made explicit. An alternative argument may be the pressure on teachers to complete the curriculum may result in the side-lining of the UN SDGs. On a positive note, the ability of students to recall and accurately describe the UN SDGs highlighted in the experiment after two months indicates the successful integration of the UN SDGs into the laboratory curriculum and into the students’ long term memory.

The final research question sought to probe the value, for students, of integrating the UN SDGs with the microscale experiment. Value for students manifested in the open items of the questionnaire, as the application of ‘chemistry concepts’ in context, this corresponds to the findings of De Jong and Taber (2014). Furthermore, the context led to the exploration of systems that interface with the chemical one i.e. ‘chemistry in context’. Students reported that they found this aspect particularly interesting and kindled a desire to know more about the UN SDGs, again this corresponds to findings of positive attitude and motivation as described by both Bennett et al. (2007) and Petillion et al. (2019).

Students’ zeal in wanting to know more about the UN SDGs and the attachment of meaningful learning to the integration of the UN SDGs was corroborated by the Likert scale findings. Furthermore, the students’ agreement with the UN SDGs as a university graduate attribute suggests how valuable the experience was to them and how open these young citizens are to the call for global action.

The Specify, Explain, Embed, Nudge (SEEN) framework efficiently allowed the researcher to integrate the graduate attribute of sustainable development into the microscale experiment. The topic of the microscale experiment, industrial pollution, allowed students to explore both chemistry concepts and chemistry in context. As proposed by the researcher, microscale experiments can have a successful dual purpose in achieving the UN SDGs as they epitomise green chemistry in terms of quantities of reagents, waste and safety but are also versatile vehicles for the integration of rich learning contexts and subsequently the UN SDGs into laboratory curricula.

Conclusion

The integration of the UN SDGs into the microscale experiment was necessary as more than 60% of the first-year students indicated that they had had no prior experience with the UN SDGs. Many practitioners may find themselves with learning materials that have subtle links to the UN SDGs and, with a little extra effort, these learning materials could be used according to the SEEN framework for students and learners to explore sustainable development and begin to develop thinking that explores chemistry in context. It is clear that the majority of students felt that the microscale experiment was enriched by the incorporation of the UN SDGs. By adding further value to microscale experiments, this study was able to contribute to meaningful learning for first-year chemistry students. There were qualitative findings of student interest as
students engaged with sustainability, which is a graduate attribute that is sorely needed in the 21st century.

Acknowledgements

The researcher would like to thank the laboratory manager, Francinah Futhane, for her help with data collection, cross-checking and laboratory set-up. The researcher would also like to thank all of the students who participated in this study. Finally, the researcher would like to thank Profs John Bradley, Fred Lubben, Peter Mahaffy and Marissa Rollnick for their support and critical input at the various stages of writing this paper.

References


TECHNOLOGY
LONG PAPERS
CHANGES IN IT AND CAT ENROLMENT AND PERFORMANCE ACROSS SOUTH AFRICAN SCHOOL TYPES
Angela Stott

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Abstract
Information technology (IT) and Computer application technology (CAT) have the potential to help bridge the digital divide associated with South African socioeconomic differences. However, the nature of enrolment and performance, across the school quintiles, for these subjects, is under-researched. In this study, the 2010-2019 matric Free State Province enrolment- and performance-data for IT and CAT, downloaded from the EMIS database, were analysed. This revealed very low enrolment in IT, particularly at lower quintile schools, with much attrition in high-, and some uptake in low- quintile schools, across the decade. CAT enrolment was found to be considerably higher in higher quintile, independent and special needs, than in low quintile, schools, and decreased across the decade in schools of all five quintiles, with a particularly pronounced decrease in low quintile schools. Performance in both subjects differed predictably across the quintiles. For both CAT and IT, performance was high and stable across the decade for quintile 5 schools. For lower quintile schools, performance was erratic across the decade for IT and tended to show improvement to 2013, decline, then improvement to 2019, for CAT. Explanations for the observed trends are proposed in terms of the Theory of Planned Behaviour. These include speculations that implementation of the Progression Law in grades 10-12 decreased already low perceptions of behavioural control and subjective norms regarding CAT in low quintile schools, contributing to CAT attrition since 2015. Interest groups are identified for further qualitative research aimed at decreasing the digital divide.

Keywords: Digital divide, Information and communication technologies (ICTs), E-education, digital literacy, poverty

Introduction
The differential impact the Covid-19 pandemic is having on the education of the rich, who have greater access to Information and Communication Technologies (ICTs), and the poor, who do not, is enlarging the digital divide (Beaunoyer, Dupéré, & Guitton, 2020). Throughout the world there is speculation that Higher Education will shift towards a greater use of distance learning even after the pandemic dies down (Ali, 2020). If these speculations are realized in developing world countries, this will provide an additional reason for such countries to improve their currently limited effectiveness at developing digital literacy skills within their Basic Education sectors (Oyedemi & Mogano, 2018). However, even before the pandemic, there was enough reason to promote digital literacy at this level. This is because basic digital literacy, coupled with school completion, is known to increase poor learners’ chances of breaking generational cycles of poverty (Chetty, Aneja, Mishra, Gcora, & Josie, 2018). Poor learners tend to have little to no access to Information and Communication Technologies, particularly
computers, for learning, at home (Oyedemi & Mogano, 2018). Therefore, they cannot be viewed as being digital natives as can their more advantaged counterparts (Brown & Czerniewicz, 2010), and so they are unlikely to develop digital literacy unless they are provided with the opportunity to do so at school. The South African (SA) Department of Basic Education (DBE) has long understood this, and has introduced a number of policies and measures regarding e-learning (e.g. Department of Education, 2004), but with largely disappointing effect despite large financial investments in providing ICTs to schools (DBE, 2015). One such measure was the provision of Computer Applications Technology (CAT) and Information Technology (IT) as school subjects since 2006.

**Literature review and problem statement**

In their review of the digital skills required by modern employers, Chetty et al. (2018) state that the generic digital literacy skills which the SA CAT curriculum (DBE, 2011a) aims to develop are highly appropriate for entry-level jobs. These skills are also considered necessary for higher education even when this is dominated by face-to-face interaction (Oyedemi & Mogano, 2018). Therefore, CAT would seem an appropriate choice both for learners planning to study at tertiary level and those planning to seek employment immediately after school, particularly for poorer learners. However, it appears that CAT and IT have not been widely embraced in South Africa (DBE, 2015), for example only 6% of schools in Limpopo offered either of these subjects in 2012. DBE (2015, p. 17) singled out the Free State (FS) as a “success story” due to the fraction of schools offering either of these subjects increasing from 42% in 2008 to 56%, in 2012, well above the stable national average of 24%.

This DBE (2015) report did not, however, indicate the relative uptake of these subjects across the five quintiles. The quintile rating indicates the socioeconomic status of the communities served. Further, no studies could be found where such a comparison has been performed. As Spaull (2013) points out, given the huge disparities in quality within SA education, data about education must be disaggregated according to socioeconomic status for meaningful insights to emerge. Further, such a comparison is highly relevant, given both the greater need for poorer learners to learn digital skills within a formal school programme (Brown & Czerniewicz, 2010), and the greater challenge that providing such a programme must surely pose in lower quintile schools which are often plagued by dysfunctionality (Van der Berg, Spaull, Wills, Gustafsson, & Kotzé, 2016). Further, it is of interest to investigate how the FS has fared regarding implementation of these subjects since being singled out as an example based on 2012 statistics. Since grade 12 examination performance is a strong driver of attitude beliefs in South Africa (Okitowamba, Julie, & Mbekwa, 2018), it is also relevant to study performance in these two subjects across the types of schools and over time.

Consequently, this study addresses these gaps in the literature through seeking to answer the research questions with regards to the Free State province in South Africa: (1) What have the school and learner enrolments in grade 12 CAT and IT examinations been, and how have these enrolment statistics changed over the period 2010 to 2019, for various types of schools? (2) How do learners from various types of schools compare in their performance in grade 12 CAT and IT examinations?
Conceptual framework

The Theory of Planned Behaviour (TPB) (Ajzen, 2011) is used as a framework to guide suggested explanations for the trends observed in the data and, consequently, suggestions for further investigation. Although the TPB is usually used to predict future behaviour, it has also been used, as it is here, to understand subject choices in post-compulsory education (Taylor, 2015). According to TPB, a person’s behaviour is affected by their intention to engage in that behaviour, modified by their perception of the control they can exert over their behaviour. A person’s intention to engage in certain behaviour is affected by their belief system, which includes attitudes, subjective norms and perceptions of behavioural control. This is represented in Figure 1, together with examples for each category of belief in terms of schools choosing to offer CAT and IT, and of learners choosing to take these subjects. Each of the examples listed is clearly complex, and undoubtedly influenced by the socioeconomic status of the community in which the school is situated (Johnson, Monk, & Hodges, 2000).

Method

This is a quantitative survey study for which data were obtained from the Free State Department of Basic Education’s (FSDBE) Education Management Information Systems (EMIS) database (FSDBE, 2020), which is in the public domain. This is part of the FSDBE’s SA School and Administration Management System (SA-SAMS) education portal. These data are submitted on a continuous basis by schools, under the responsibility of each principal. The FS was an early adopter of the SA-SAMS, which, according to van Wyk (2015), increases the validity of
the data available from the EMIS database. The subject statistics per school per district for the period 2010-2019 were downloaded from this database and combined into a single spreadsheet. Additionally, current quintile designations per school, obtained from the National EMIS School Masterlist database (DBE, 2020b), were used. Since special-needs and independent schools are generally not assigned a quintile rating, these were categorised separately. Special-needs schools cater for learners with severe learning, physical or behavioural difficulties (DBE, 2020a) and independent schools are privately governed (RSA, 1996), and therefore have the option of writing examinations set by the Independent Education Board (IEB) rather than the National Senior Certificate (NSC).

Excel’s pivot table, t-test and graphing functions were used for data analysis, guided by the research questions. To answer the first research question, regarding the enrolment in CAT and IT across the school types, numbers of schools and of candidates per school, for the grade 12 CAT and IT examinations, as well as total numbers of schools and candidates, were used, per school type per year. To answer the second research question, regarding the performance of learners in CAT and IT, two measures of performance were used: pass rate and average mark. For each of these, the mean for each school was accessed, and the means of these, for each school type, per year, were calculated. Since pass rates tend to be focused on in examination reports such as DBE (2020a), and therefore they are more likely to affect attitude beliefs, these were particularly focused on, with the pass mark taken as 30%. In addition to the descriptive statistics used, t-tests were performed for the 2010 and 2019 low (quintiles 1-3) vs high (quintiles 4-5 and independent) socioeconomic groupings for mean percentages of grade 12 CAT candidates per total grade 12 candidates in schools which offered CAT that year, average CAT marks, and pass rates. Significance was assumed at p<0.01. The IT data were too limited to justify statistical analysis.

There is some discrepancy between the numbers of grade 12 candidates in the data used here and those published in the Department of Education examination reports. For example, DBE (2020a) reports that 25 572 FS learners sat the grade 12 examination in 2019, whereas for the same year, the total number of candidates in quintile 1-5 and special-needs schools, derived from the downloaded documents, is 28 949 (see Tables 1 and 2). This total was determined as the sum of learners taking English Home and English First Additional, Languages, since all learners must take either, but may not take both, of these. Since the EMIS database is intended for use by the DBE, researchers and practitioners, in order to inform practice (van Wyk, 2015), it is assumed that errors suggested by this discrepancy do not significantly threaten the validity of the trends revealed in this study.

**Findings**

Figures 2 and 3 and Figures 4 and 5, represent the enrolment and performance in IT and CAT, respectively, across all the years from 2010 to 2019. Additionally, the data extracted for the first and last years (2010 and 2019) analysed, are represented in Table 1, showing data for IT, and Table 2, for CAT. The following assertions summarise the findings in answer to the research questions. Each assertion is then argued for below:
• The enrolment in Information Technology (IT) is very low throughout the Free State, particularly in low quintile schools. Across the last decade enrolment has decreased drastically in quintile 5, and increased slightly in quintile 1-4, schools.

• IT performance is considerably better and more stable across time, for learners in quintile 5 than 1-4 and independent schools.

• The enrolment in Computer Applications Technology (CAT) is high in the Free State, relative to national statistics, across the quintiles. However, CAT has always been considerably more prevalent in schools for special-needs and richer learners. Enrolment in general, as well as the gap in enrolment between schools serving the poor and the rich, has widened considerably, particularly since 2015, due to even greater attrition of schools and learners from lower than higher quintiles in this period.

• CAT performance is significantly better at schools catering for richer learners. Pass rates have been high and stable for high quintile schools. Low quintile schools’ CAT pass rates have increased, dropped, then increased again across the decade.

Low and changing relative enrolment in IT

As can be seen in Table 1, in 2019 only 17 of the 349 FS Schools appearing in the database (i.e. 5%), offered Information Technology (IT). Ten of these 17 were quintile 5 schools. Also, very few (1% or fewer) FS learners took IT in 2019. As can be seen in Figure 2, from 2010-2019, the number of learners taking IT in grade 12 decreased drastically for quintile 5 schools and increased slightly for quintile 1-4 schools. This can also be seen by the changes in bubble sizes in Figure 3. These sizes indicate the number of grade 12 learners who took IT as a fraction of the total number of grade 12 learners in that type of school in that year. It should be pointed out, however, that the largest bubble size in this figure represents only about 3% of learners of that type of school, and the smallest bubble sizes represent less than 1%.

![Figure 2: Number of Free State learners taking grade 12 IT per school type per year](image)

Differential performance in IT

Figure 3 indicates FS IT pass rates over time. Independent schools have been excluded here due to their extremely small IT enrolment numbers in only two of the 10 years. IT was only introduced into any FS quintile 1 and 2 schools in 2011 and 2012 respectively. The IT pass
rates of quintile 1-3 and, to a lesser degree 4, schools have been erratic across the years. The small numbers of learners taking IT in these schools contributes to the instability of this statistic. Quintile 5 schools also clearly outperform other schools on mean IT marks. This can be seen in Table 1. For the years not shown in this table, the mean for IT for quintile 5 FS schools ranged from 51% (2012) to 63% (2018), with a mean across the decade being 56%. During this time, quintile 4 schools occasionally performed within this range, but their performance was highly variable, with their means for class averages for IT ranging from 34% (2017) to 58% (2010) and having a mean across the decade of 49%. The low quintile (1-3) and independent schools performed consistently lower than this, with their means across the decade being 37%, 42%, 36% and 34% respectively.

![Figure 3: Grade 12 IT pass rates across time for various types of Free State schools. Bubble size represents the fraction of grade 12 learners of that school type that took IT.](image)

**Decreasing enrolment in CAT, particularly for poorer learners**

As can be seen in Table 2, in 2010 roughly a third of quintile 1 and 2 schools, a half of quintile 3 and independent, and two thirds of quintile 4 and 5 and special-needs schools offered CAT. As shown in Figure, the numbers of schools offering grade 12 CAT increased slightly from 167 in 2010 up to 189 in 2013, with learner numbers fluctuating slightly around approximately 4 000 with a maximum in 2015 of 4 245, after which the numbers of schools offering, and, particularly learners taking, CAT in the FS decreased dramatically to only 143 schools, 2 729 learners, in 2019. The increase in CAT learner numbers between 2014 and 2015 was due to increases in quintile 1-4 learners (1 970 to 2 520), while the numbers of CAT learners in quintile 5 and independent schools dropped slightly (1 857 to 1675). The attrition of schools from 2013, and learners, from 2015, was particularly pronounced in low quintile schools. For example, quintile 1 schools dropped from a 2013 high of 39% of schools offering and 8% of learners taking CAT, to only 18% of schools and 3% of learners, in 2019. It is known that the number of CAT candidates has decreased nationally over time (DBE, 2020a). However, as a conservative comparison, if the national statistic for CAT and IT enrolment, which was stable at 24% of schools between 2008 and 2012 (FSDBE, 2015), had been maintained, then at the
FS’s lowest point to date (2019), all but quintile 1 schools (at 18%) still had higher CAT enrolment (see Table 2) than the national average for both CAT and IT combined.

The bubble sizes in Figure represent the numbers of grade 12 learners taking CAT, as a fraction of the total number of grade 12 learners in that type of school in that year. It is clear from this that a high proportion (55% in 2019) of learners at special-needs schools took CAT, although, as shown in both Table 2 and Figure, the absolute number of such learners is very low. The sizes of the bubbles for quintile 4 and 5 and independent schools are clearly larger than for quintile 1-3 schools. In a slightly different measure of enrolment, Table 2 shows statistically significantly higher fractions of learners taking CAT in schools for the rich even when only schools which offer CAT are included. Although all the bubble sizes in Figure 3 decrease across the years, this decrease is more noticeable for the low quintile schools since the decrease forms a greater fraction of their lower maximum value. This corresponds to the data given in Table 2: in 2019 only 3-6% of learners in quintile 1-3 schools took grade 12 CAT in the FS. This was a decrease of approximately 63% from the 2011 highs of 8-16%. In contrast, 22-28% of learners in quintile 4 and 5 and independent schools, and 55% of learners in special-needs schools took grade 12 CAT in the FS in 2019. This is a less pronounced (27% and 15%) decrease for quintile 4 and 5 schools, from their 30% and 33% maximums in 2011. The small absolute numbers of learners in independent and special-needs schools make the fluctuations in their data less meaningful than for the other school types.

![Figure 4: Number of Free State learners taking grade 12 CAT per school type per year](image)

**Differential, fluctuating, but relatively high, performance in CAT**

As is visually evident in Figure and statistically evident in Table 2, quintile 1-3 school performance in CAT was considerably worse than that of other schools in 2010. Their performance increased steadily until 2013, followed by drops in 2014 or 2015, after which their pass rates have risen. In 2019 the average CAT pass rate of low quintile schools was 96%. Although this was found to be statistically significantly lower than the 99% pass rate of quintile 4-5 and independent schools, this difference is considerably less than the 86%-94% comparisons for 2010 (see Table 2). This high CAT pass rate, relative to other subjects, is consistent with national averages which tend to be in the high 80s or 90s (DBE, 2020a).
Comparison of the means of class averages between the various types of schools reveals that quintile 4 and 5 schools achieved approximately 10% higher, with their means across the decade being 52% and 53% respectively, than low quintile and special-needs schools (41%-44%). The CAT mean for independent schools across the decade was 46%. The means for each school type were found to be fairly stable across the years, with all being 40% or higher.

Figure 5: Grade 12 CAT pass rates across time for various types of Free State schools. Bubble size represents the fraction of grade 12 learners of that school type that took CAT.

Discussion
The purpose of this discussion is to suggest possible explanations for the observed trends in terms of the Theory of Planned Behaviour.

Low general enrolment in CAT and IT, particularly in poverty

Chetty et al. (2018) ascribed the low uptake of CAT among SA learners to universities not including CAT in their list of designated subjects used to determine university entrance. It is likely that this practise, revoked in 2018 (DHET, 2018), could have developed the attitude belief that CAT is more appropriate for learners who do not aim to attend university. One might expect special-needs schools to aim at preparing their learners for a vocation without higher education, given the disabilities of their learners, so that a belief that CAT is an appropriate subject for such a focus seems consistent with the high proportion of learners enrolled in CAT in special-needs schools. However, nationally, in 2019 approximately 57% of special-needs learners achieved a Bachelor pass which qualifies a learner to apply for university entrance, as opposed to the national average of only 36.9% in the same year, ranging from 28% for quintile 1 schools to 56% for quintile 5 schools (DBE, 2020a).
Table 2: Enrolment and performance for grade 12 IT in the Free State for selected years

<table>
<thead>
<tr>
<th>Year</th>
<th>Quintile / Category</th>
<th>Total grade 12 examination numbers</th>
<th>Grade 12 IT examination numbers</th>
<th>Percentages that grade 12 IT numbers are of the totals (%)</th>
<th>Mean of grade 12 IT marks (%)</th>
<th>Mean grade 12 IT pass rates (%)</th>
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<td>14</td>
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</table>

Table 11: Enrolment and performance for grade 12 CAT in the Free State for selected years

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<th>Year</th>
<th>Quintile / Category</th>
<th>Total grade 12 examination numbers</th>
<th>Grade 12 CAT examination numbers</th>
<th>Percentages that grade 12 CAT numbers are of the totals (%)</th>
<th>Mean of grade 12 CAT marks (%)</th>
<th>Mean grade 12 CAT pass rates at 30% (%)</th>
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</thead>
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<td>Learners</td>
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<td>34</td>
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</tbody>
</table>

*Mean of grade 12 learners who did CAT, as a percentage of total learners in schools that offered CAT
Therefore, given the low likelihood of learners, particularly from low quintile schools, attending university, the potential misconceived attitude belief that CAT is inappropriate for preparing one for university does not seem appropriate to explain the low enrolment in CAT, particularly in low quintile schools. A more plausible explanation for low enrolment in both CAT and IT seems to be low perceptions of behavioural control resulting from poverty. Learners who depend on the school to provide them with access to computers do not have control over their learning of CAT and IT, particularly if their schools limit this access, as is known to occur in low quintile SA schools (Stott, 2020). The dysfunctionality prevalent in such schools also results in teachers feeling less supported (Johnson et al., 2000), and therefore less able to control their computer laboratories and the equipment necessary to teach and assess CAT and IT. Further, although it appears that most schools in the FS have been donated electronic equipment, teachers’ digital literacy tends to be low, particularly in lower quintile schools (Jacobs, 2018). This would mean that technical knowledge such as how to establish a school network, how to install anti-virus programmes and establish a school computer management policy, all of which are needed for smooth implementation of CAT and IT (DBE, 2011a), is unlikely to be present in lower quintile schools. Further, it is known that internet access, which is required for some sections of the CAT and IT curricula (DBE, 2011a), is limited in lower quintile schools (DBE, 2015). Additionally, the threat of computer theft is particularly high in the poverty-stricken areas in which low quintile schools are situated, further undermining the feelings of control teachers and learners may possess over their behaviour with regards to computer usage.

This view is consistent with SA studies (e.g. Govender, 2012) which found that perceived behavioural control tends to be the limiting factor in teachers’ decisions to use ICTs and that subjective norms regarding ICT-usage tend to be low. SA department officials, principals, parents and learners tend to exert little pressure on teachers to integrate ICTs into their teaching. Particularly in low quintile schools, this is unsurprising, since poor learners and parents tend to have less power than their richer counterparts and in a context where there are multiple challenges to education, even at the most basic level (Van der Berg et al., 2016), it is understandable that it may be considered unreasonable to expect teachers to overcome the technical and security difficulties involved in ICT-usage (Johnson et al., 2000).

Qualitative findings regarding low quintile CAT teachers’ challenges (e.g. Fambaza, 2012) are consistent with this view. These teachers face many material, technical and security challenges which add additional stress to their teaching, decreasing their perceptions of control over ICT-usage and decreasing the likelihood that it is considered reasonable for subjective norms to expect ICT-usage. These studies also reveal that CAT teachers in low quintile schools tend to have low content knowledge due to having had little to no formal training in teaching CAT. Low content knowledge decreases a teacher’s perception of behavioural control (Pelgrum, 2001), and it seems reasonable to expect that low teacher content knowledge would result in low learner performance which would harm attitude beliefs regarding the desirability of taking and offering the subject. This is consistent with the low IT performance of learners in low quintile schools across the decade, but not with the high CAT performance observed for learners from all quintiles in the latter part of the decade. However, the mark analysis performed here used only means per group which could be masking more localised trends.
**Trends across the decade**

The trends observed across the years may be related to changes in policies regarding grade 12 examinations. In 2013 the DBE implemented the progression law in the Further Education and Training (FET) phase. According to this law, learners who had failed once within this phase had to be progressed to the next grade regardless of achievement level. This resulted in increased numbers of learners, many with low skill levels due to possibly having passed few if any previous grades based on merit, being progressed into grade 12 in 2015 (Stott, Dreyer & Venter, 2015). Although quintile 5 and independent schools were hardly affected by this change, the situation placed much stress on teachers in low quintile schools (Stott et al., 2015). This was somewhat ameliorated from 2016 to 2019 by the policy on multiple examination opportunities (MEO), according to which progressed learners could split the subjects they sat for examination across two years (DBE, 2019).

In the light of this, the following explanation is proposed regarding the observed trends in CAT numbers and performance in the FS across the last decade. Following donation of ICT laboratories to low quintile schools in the 2000s (FSDBE, 2015), the number of schools implementing CAT increased, with numbers probably peaking in 2011 to explain the observed manifestation of this peak in the grade 12 data in 2013. CAT learner numbers in low quintile schools increased to 2015, even after their school numbers started to decline, coupled with a 2014 and / or 2015 dip in pass rates in low quintile schools. These findings correspond, somewhat, to Stott et al.’s (2015) findings that the progression law resulted in swollen 2015 numbers, and depressed marks in lower quintile schools as weaker learners who had been kept at grade 10 level before implementation of the progression law, were flushed into grade 12. The decline in numbers of learners, particularly from low quintile schools, taking CAT after 2015 may be related to some learners choosing the MEO option and so splitting their subjects across two years, a practice which might also account for some of the discrepancy in the data extracted from EMIS relative to that published in national reports.

However, the decrease in schools offering CAT cannot be explained by the MEO option. Therefore, the following explanation is proposed. From 2013 onward, the burden low quintile schools experienced in having to prepare progressed learners to write matric examinations, affected attitude beliefs, subjective norms and perceptions of behavioural control in manners which decreased the likelihood that CAT would be sustained, resulting in phasing out of CAT in many of these schools, with this particularly beginning to show in grade 12 statistics after the 2013 grade 10s had reached grade 12 in 2015. Since CAT requires more resources and effort to implement, given its practical nature and reliance on equipment, than more traditional subjects do, the attitude would likely be that the effort required to implement CAT would not be worthwhile during this time of additional stress. When significant role players develop such an attitude, the subjective norms incentivising action are further reduced. Finally, these stressed conditions would have further decreased the teachers’ and learners’ perceptions of behavioural control which, as discussed above, were likely already low.

It should be noted, however, that blaming CAT attrition on the stress which having to get progressed learners through the system caused is insufficient, since this attrition was also observed in quintile 5 schools which have few progressed learners (Stott et al., 2015). Further,
the trend in IT uptake by low quintile schools defies the trend this explanation would predict for IT as well as CAT. Since the IT numbers are very low, this finding does not necessarily negate the explanation for CAT trends, suggested above. However, it does suggest that the situation is more complex than presented here. Clearly further qualitative investigation is needed into reasons for the trends.

**Conclusion**

One of the assertions given in the Bridges.org (2001) report “Spanning the digital divide” is that interventions aimed at decreasing the digital divide might in fact increase the divide further as richer communities benefit even more from such interventions than poorer communities. This study suggests that this applies to SA’s implementation of IT and, particularly, CAT. As shown in this study these subjects are more prevalent in schools serving richer learners than those serving the poor communities most in need of formal education to develop digital literacy. This trend may be an example of the so-called Matthew effect, where those who already possess knowledge, skill, resources and functionality are more likely to develop more of these. The schools that operate against this principle are of interest. I suggest, therefore, that it would be valuable to examine what lessons can be learnt from (1) the special-needs schools that have high CAT enrolments and pass rates despite having learners with physical, mental or behavioural challenges; (2) the low quintile schools that have increased their enrolments and performance in IT across the last decade; (3) the low quintile schools that have not succumbed to CAT attrition. Perhaps such case studies may help reverse the trends which suggest loss of opportunity, wasted electronic resources in schools and intensification of the digital divide in South Africa.

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STUDENTS’ PERCEPTIONS OF E-ASSESSMENT IN THE CONTEXT OF COVID-19: THE CASE OF UNISA
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Abstract
The purpose of this study was answering the question: What are Information and Communication Technology (ICT) students’ perceptions of e-assessment? Its importance is justified regarding positioning these students’ education towards the development agenda in Southern Africa despite disruptions. It draws on the latest relevant findings on ICT programming teaching and learning and is located within relevant conceptual/theoretical frameworks on assessment. In quantitative aspects of the design, issues of reliability and validity were considered, while in qualitative aspects, issues of dependability and interpretation were important. Results presented are encouraging: e-assessment enhanced quality aspects of students’ learning, and helped to improve the quality of assessment in higher education. Discussion of the results shows insight and originality by suggesting implications and making recommendations that are applicable and useful. In conclusion and answer to the research question, students’ perceptions of e-assessment were positive, valuing features regarding e-assessment providing faculty with feedback to improve learning.

Introduction
These days, the latest findings on topics such as the development of heuristics to make it easier to use mobile e-commerce applications in Africa seem to dominate the headlines (Ajibola & Goosen, 2017). Information and Communication Technologies (ICTs) are involved in many different sectors of everyday life, and also have an impact on improving the learning environment and processes. With increasing numbers of students competing for limited placement opportunities, new innovations for positioning ICT education towards the development agenda in Southern Africa during disruptive times are required - Alruwais, Wills and Wald (2018) therefore investigated the advantages and challenges of using e-assessment.

The increased opportunities for especially e-learning mentioned in the previous paragraph included the growth in Massive(ly) Open Online Courses (MOOCs), which are changing education environments, increasing students’ access and the flexibility they have when engaging with education. In a context like that, Falkner, et al. (2020) explored meaningful assessment at scale as a way of helping instructors to assess online learning. One such a MOOC offering provides students in Southern Africa with access to educational technologies against the background of ICT for Development (ICT4D) in the 21st century (Goosen, 2015a; 2018b). Such educational technologies could also be used for growing innovative e-schools in the 21st century through e.g. a community engagement project (Goosen, 2015b).

The purpose of the study reported on in this paper submission to the 29th conference of the Southern African Association for Research in Mathematics, Science and Technology
Education (SAARMSTE 2021) was to answer the research question: What are ICT programming students’ perceptions of the e-assessment put into place to position these students’ education towards the development agenda in Southern Africa during disruptive times? The University of South Africa (UNISA) had recently implemented an e-assessment mode in the Learning Management System (LMS) it used and the importance of this needed to be justified by examining students’ perceptions of this mode of assessment.

Comparatively, the purpose of the chapter by Goosen and Van Heerden (2019b, p. 26) was related to the provisioning of students’ perspectives on the uptake of Virtual Learning Environment (VLE) technologies, which were being used for student support and towards self-directed learning in an ICT course “taught in an Open and Distance e-Learning (ODEL) environment.”

Now that the research question and purpose have been clearly stated and the importance of these had been justified, the next section of this paper will draw on the latest and most relevant research findings on topics with regard to ICT programming teaching and learning. In the section thereafter, the study is located within a relevant theoretical and conceptual framework with regard to assessment. The paper will show how it is consistent, for example, how the methodology is appropriate to the research question, as well as how the design and execution of the methodology is adequate in relation to the research question. For the quantitative aspects of the mixed methods research design used, the paper indicates how issues with regard to reliability and validity were considered, while for the qualitative aspects of the research design, issues in terms of dependability and interpretation were important. The results, which are consistent with the methodology, are clearly and correctly presented, while the discussion of the results shows insight and originality by suggesting implications and making recommendations that are applicable and useful. The research question is answered in the conclusion, and the conclusions that the paper comes to are justifiable in terms of methodology and the applicable results presented. The paper is therefore original, and it does contribute towards scholarly debates in fields with regard to positioning ICT programming students’ education towards the development agenda in Southern Africa during disruptive times.

**Literature review**

This section of the paper will draw on the latest and most relevant research findings on topics related to ICT programming teaching and learning. The computer programming performance of first-year students worldwide is of great concern, whether such students’ tuition takes place in a face-to-face context and/or at a distance and/or by using e-learning management system technologies. Goosen and Van Heerden (2015) were of the opinion that in a face-to-face context, it was, however, somewhat easier to support and teach these students.

Such ICT programming courses tend to suffer from low retention rates, which are believed to be because of difficulties with regard to the learning of programming concepts. Since another possibility was related to how programming ability was assessed, Öqvist and Nouri (2018) evaluated the effect of assessment mode on the performance of students learning programming, in order to determine whether coding by hand or on the computer was the better option.
The resulting low throughput rates for these computer programming courses across the world, especially for first-year level students, have been investigated through research for many years, leading to the publication of research on different methods with regard to teaching and/or pedagogy, e-learning, as well as assessments used in an Open and Distance e-Learning environment to promote self-directed learning (Van Heerden & Goosen, 2019).

As computer science enrolments continue to surge, examination grading is requiring significant instructional resources, with online grading platforms having been developed recently and being adopted at an increasing number of Higher Education Institutions (HEIs). However, according to Cao, Porter, Liao and Ord (2019), a comparison of examination grading techniques (paper or online), in terms of their effectiveness, was needed.

The aim of the research by Goosen and Van Heerden (2017) was related to going beyond the horizon of learning programming by providing students’ perceptions on them taking up educational technologies on the VLE to effectively teach and meaningfully learn, towards addressing the challenges of an ICT course. Such research needs to take place within a framework that establishes partnerships between HEIs and e-students beyond familiar territories towards supporting and enhancing such students’ success along various dimensions, with a focus on the adoption of educational technologies (Vorster & Goosen, 2017). An example of the latter would be using vodcasts to teach programming in an ODeL environment (Van Heerden & Goosen, 2012).

It has therefore become a challenging and important issue to work towards fostering students’ concepts and skills with regard to computer programming. Scholars, such as Wang, Hwang, Liang and Wang (2017), believe that programming tuition could promote students’ performance in terms of higher order thinking; however, many schoolteachers have reported on the difficulty of teaching such programming courses. Despite several previous studies having attempted the development of friendly user interfaces towards easing students’ cognitive loads, teaching these programming courses remains a huge challenge for most schoolteachers. The latter authors attempted to use online peer-assessment for enhancing students’ computer programming performance, critical thinking awareness and attitudes towards programming.

“The purpose of the study reported on in” the SAARMSTE paper by Goosen and Van Heerden (2019a, p. 215) was answering a research question on the extent to which student-centred education was being created on the LMS for first-year programming students in an Open and Distance e-Learning environment. As authors, we were of the opinion that this justified the importance of promoting research-based opportunities through relevant and quality Information Technology (IT) education.

The latest chapter by Van Heerden and Goosen (2020) presented research findings on topics related to the promotion of the growth of Fourth Industrial Revolution Information Communication Technology students, as well as the implications of these for Open and Distance e-Learning.
Conceptual and theoretical framework

In this section of the paper, concepts around assessment will be located within a relevant conceptual and theoretical framework. According to Khairil and Mokshein (2018), in recent years, the growth in terms of teaching and learning had been transforming the education world, where education is no longer being limited to only certain places and times, due to the full utilisation of ICTs and 21st century e-assessment.

Detailing students’ evaluation of the use of online summative assessment in an undergraduate financial accounting course, according to Marriott (2009), assessment is described as any of the processes, which appraise individuals’ knowledge, understanding, abilities and/or skills, and these are inextricably linked to courses’ or programmes’ intended learning outcomes.

Assessment also forms “an integral part of all” learning (Das, et al., 2017, p. 38). In different formats, formative assessment have been evolving as a means for finding the learning gaps in terms of what students already know, compared to what it is that they need to know - The latter authors therefore used a feedback-based cross sectional study conducted among basic science students enrolled in a Medical Degree (MD) programme to establish the impact of formative assessment on the outcome of summative assessment.

Summative assessments are typically used for evaluating ultimate student outcomes in terms of how much learning has been occurring and customarily occur less frequently than formative assessments during instruction. As few studies had examined how the delivery of summative assessments can be used for reducing the achievement gap, as well as for influencing and improving the learning of students, who come from at-risk groups, the study by Agboola and Hiatt (2017) investigated these phenomena.

In line with two of the SAARMSTE pillars (education and mathematics), Iannone and Simpson (2017) reported on a study that compared the perceptions of university students of summative assessment in terms of the role of context across these two distinct disciplines at two of the research-intensive institutions in the United Kingdom (UK).

The paper by Goosen and Van Heerden (2013a) introduced research with regard to project-based assessment aspects being investigated in terms of influencing and improving students’ pass rates, in especially ICT courses at an Open and Distance e-Learning institution.

In their article, Goosen and Van Heerden (2013b) introduced a literature review explaining the main arguments relating to project-based assessment and learning in an Information Technology course offered in an Open and Distance e-Learning context.

The aim of the research project reported on in Goosen and Van Heerden (2018) related to providing various ICT tools and tips in terms of the assessment approaches at UNISA. The learning management system was used for addressing the first-year experience of students in an ICT Open and Distance e-Learning course.

The study by Alsadoon (2017) explored students’ perceptions of e-assessment at Saudi Electronic University. At the time, that university had recently implemented such an e-assessment mode in the LMS it was using. Therefore, it was important to examine the perceptions of these students of the e-assessment mode.
The quantitative study presented by Wing (2018) evaluated the effects that formative and summative assessments had on students’ academic performance, connectedness, learning and satisfaction in an online three-credit university course for fourth-year level healthcare students.

Mohamadi (2018) compared the effects of online formative and summative assessments on the writing ability of 130 Iranian English as Foreign Language (EFL) junior university students. Three assessment interventions in terms of the writing performance of participating students were investigated across 27 sessions using a pre-test/post-test time series design. These interventions had included online portfolio writing assessments and online summative assessments conducted individually, as well as online collaborative formative assessments.

**Methodology**

Regarding the mixed methods research design used, with similarities to those of Alsadoon (2017) and Iannone and Simpson (2017), the study reported on in this paper was exploratory, and was meant to reveal UNISA ICT programming students’ perceptions of e-assessment.

All undergraduate students from UNISA, who could have been involved in the examination on 15 June 2020, were considered as potential participants in this study. By the end of the first semester of 2020, 492 students had been admitted to this particular examination, an e-assessment, which had been implemented only recently. The population numbers of students involved in the examination are provided in Table 1.

<table>
<thead>
<tr>
<th>Table 12. Numbers of students involved in the examination on 15 June 2020.</th>
</tr>
</thead>
<tbody>
<tr>
<td>From semester 2, 2019</td>
</tr>
<tr>
<td>Admitted to the examination</td>
</tr>
<tr>
<td>Projects were submitted successfully</td>
</tr>
</tbody>
</table>

While all of these students were invited to participate in the study by email, 159 sample students voluntarily responded to the self-designed online survey used for data collection, which had been based on that of Alsadoon (2017).

This survey contained seventeen items for collecting data on students’ opinions of the e-assessment mode. The first four items were designed to collect data about how many of these e-assessments students had been able to complete the examination, etc. and had between two (No/Yes) and ten options each. The remainder of the items were rated on a five-point scale from totally disagree (1) to fully agree (5), apart from the last item, which provided students with an opportunity to supply qualitative comments.

“The aim of the research reported on in" the paper by Goosen and Van Heerden (2016, p. 275) was related “to providing an initial quantitative perspective on” e-students’ uptake of e-learning environment “tools towards effective teaching for meaningful e-learning to address the challenges related to” an online and Open and Distance e-Learning context, while Goosen and Mukasa-Lwanga (2017) took educational technologies in distance education beyond the horizon with qualitative perspectives.

Measures were put into place to ensure that the design and execution of the methodology were adequate in relation to the research question posed: For the quantitative aspects of the research
design, issues of **reliability** and **validity** were considered, while for the **qualitative** aspects of the design, issues of **dependability** and **interpretation** were important.

**Internal validity** was ensured by obtaining advice from an expert researcher on the questions to be used (Goosen, 2015a), with the instrument having been modified according to these suggestions (Alsadoon, 2017). The original instrument had been piloted with twenty students to ensure clarity and **reliability**.

In light of the importance of **dependability**, an effort was made to provide students’ comments in their own words, so that readers would be convinced that the data collected had led to the results presented by the researchers. Goosen (2018a) further indicated that triangulation between **quantitative** aspects and respondents’ **qualitative** perceptions as data was critical for facilitating **interpretation**. Collected data were analysed using averages and standard deviations.

The computer lecturer for this module had been available via e-mail, Microsoft Teams and telephonically on the day of the examination from 7:00 am to 2:00 pm to address all issues, questions, concerns and panic attacks, which occurred.

No students requested assistance with downloading the paper. Three students e-mailed regarding problems they experienced when it came to uploading the examination; their e-mailed assignments had been accepted. One student claimed to have had load shedding and one student claimed a crashed laptop after online submissions closed; both were informed that they could no longer submit, as it is an examination. One student requested a file substitution, as the wrong file was uploaded.

**Findings**

More than half of the respondents indicated that they were able to complete the ICT1512 examination on 15 June 2020 (see Table 2).

For Table 3, please note that students could select more than one option. Of the 144 responses indicated for this item, the option most often selected was that students did not have enough time. Many students also did not have the necessary equipment to have done the examination, and/or encountered technical problems when they attempted to submit.

**Table 13.** Did you complete the ICT1512 examination on 15 June 2020?

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>71</td>
<td>45%</td>
</tr>
<tr>
<td>Yes</td>
<td>88</td>
<td>55%</td>
</tr>
</tbody>
</table>
Table 14. The ICT1512 online examination was problematic, because:

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I did not have access to a computer</td>
<td>16</td>
<td>11%</td>
</tr>
<tr>
<td>I did not have access to the internet</td>
<td>11</td>
<td>8%</td>
</tr>
<tr>
<td>I did not have enough time</td>
<td>27</td>
<td>19%</td>
</tr>
<tr>
<td>I did not understand what was required of me for the examination</td>
<td>10</td>
<td>7%</td>
</tr>
<tr>
<td>The project was too difficult</td>
<td>9</td>
<td>6%</td>
</tr>
<tr>
<td>I encountered technical problems when I attempted to submit</td>
<td>19</td>
<td>13%</td>
</tr>
<tr>
<td>I prefer writing the examination by hand</td>
<td>13</td>
<td>9%</td>
</tr>
<tr>
<td>If I had the necessary equipment, I would have done the examination</td>
<td>21</td>
<td>15%</td>
</tr>
<tr>
<td>The project was too difficult</td>
<td>18</td>
<td>13%</td>
</tr>
<tr>
<td>There was power outage in my area on the day of the examination</td>
<td>16</td>
<td>11%</td>
</tr>
</tbody>
</table>

More than three-quarters of the 88 students (73; 83%), who responded to this question, preferred the online portfolio examination to the handwritten examination (see Table 4).

Table 15. I prefer the online portfolio examination to the handwritten examination.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>15</td>
<td>17%</td>
</tr>
<tr>
<td>Yes</td>
<td>73</td>
<td>83%</td>
</tr>
</tbody>
</table>

For Table 5, please note that students could select more than one option. Of the 154 responses indicated for this item, more than a third of the students (54; 35%) felt that they could practically show what they had learnt, while a quarter of them (38) were able to use their examination project as proof of ability when required. Bearing in mind that this examination took place during a lockdown period in South Africa, due to the COVID-19 pandemic, it is significant that a quarter of these students (38) preferred to not have travelled to complete their examination.

The largest group of students (63; 40%) fully agreed that e-assessment helped to improve the quality of assessment in higher education, while more than a third of them (54; 34%) agreed (see Table 6). Only two (1% of the) respondents totally disagreed with this statement.

Similar to results in Table 6, the largest group of students (63; 40%) fully agreed that e-assessment enhanced quality aspects of their learning, while just less than a third of them (50;
31%) agreed (see Table 7). Only one (1% of the) respondent(s) totally disagreed with this statement.

**Table 16.** I prefer the online examination portfolio, because:

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I am able to use my examination project as proof of ability when required</td>
<td>38</td>
<td>25%</td>
</tr>
<tr>
<td>I can practically show what I have learnt</td>
<td>54</td>
<td>35%</td>
</tr>
<tr>
<td>I do not have to memorize a lot of theoretical work</td>
<td>24</td>
<td>16%</td>
</tr>
<tr>
<td>I do not have to travel to complete my examination</td>
<td>38</td>
<td>25%</td>
</tr>
</tbody>
</table>

**Table 17.** E-assessment helps in improving the quality of assessment in higher education.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>5%</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>34%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>63</td>
<td>40%</td>
</tr>
</tbody>
</table>

**Table 18.** E-assessment enhances quality aspect of my learning.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>5%</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>23%</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>31%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>63</td>
<td>40%</td>
</tr>
</tbody>
</table>

The numbers of students, who either fully agreed (60; 38%) or agreed (59; 37%) that e-assessment provided faculty with feedback to improve learning, were almost equal, while only two (1% of the) respondents totally disagreed with this statement (see Table 8). This item displayed the joint-lowest standard deviation (0.91).

**Table 19.** E-assessment provides faculty with feedback to improve learning.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>3</td>
<td>33</td>
<td>21%</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>37%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>60</td>
<td>38%</td>
</tr>
</tbody>
</table>
Almost half of the responding students fully agreed (76; 48%) that e-assessment enhances self-learning, while almost a third (49; 31%) agreed (see Table 9). Only two (1% of the) respondents totally disagreed with this statement.

**Table 20. E-assessment enhances self-learning.**

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>3%</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>17%</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>31%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>76</td>
<td>48%</td>
</tr>
</tbody>
</table>

More than a third (58; 36%) of the responding students fully agreed that e-assessment reduces examination stress, while just less than a quarter each of them (38; 24%) either agreed or neither agreed nor disagreed (see Table 10). The number of respondents (15; 9%), who totally disagreed with this statement, was significantly higher than most of the other items this far reported: while the standard deviation for the latter were all below 1, for this item it was 1.28.

**Table 21. E-assessment reduces examination stress.**

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>15</td>
<td>9%</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>24%</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>24%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>58</td>
<td>36%</td>
</tr>
</tbody>
</table>

Well over half of the responding students fully agreed (91; 57%) that e-assessment improved their technical skills, while just less than a quarter of them (37; 23%) agreed (see Table 11). Only one (1% of the) respondent(s) totally disagreed with this statement. This item displayed both the highest average (4.33) and joint-lowest standard deviation (0.91).

**Table 22. E-assessment improves my technical skills.**

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>4%</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>15%</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>23%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>91</td>
<td>57%</td>
</tr>
</tbody>
</table>

More than a third (57; 36%) of the responding students fully agreed that e-assessment was appropriate for all subjects, while more than a quarter of them (44; 28%) neither agreed nor disagreed (see Table 12). This item showed the highest standard deviation (1.34) of all those included in this study.
The largest group of students (52; 33%) neither agreed nor disagreed that e-assessment was appropriate for all students (see Table 13).

**Table 23.** E-assessment is appropriate for all subjects.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>16</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>11%</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>28%</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>15%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>57</td>
<td>36%</td>
</tr>
</tbody>
</table>

The largest group of students (47; 30%) neither agreed nor disagreed that e-assessment did not require advanced technical skills from students (see Table 14).

**Table 24.** E-assessment is appropriate for all students.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>14</td>
<td>9%</td>
</tr>
<tr>
<td>2</td>
<td>31</td>
<td>19%</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>33%</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>18%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>34</td>
<td>21%</td>
</tr>
</tbody>
</table>

More than a third of responding students (58; 36%) agreed that e-assessment promoted the application of a variety of questions, while just less than a third of them (47; 30%) fully agreed (see Table 15). Only two (1% of the) respondents totally disagreed with this statement.

**Table 25.** E-assessment does not require advanced technical skills from students.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>24</td>
<td>15%</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>14%</td>
</tr>
<tr>
<td>3</td>
<td>47</td>
<td>30%</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td>21%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>32</td>
<td>20%</td>
</tr>
</tbody>
</table>

More than a third of responding students (58; 36%) agreed that e-assessment promoted the application of a variety of questions, while just less than a third of them (47; 30%) fully agreed (see Table 15). Only two (1% of the) respondents totally disagreed with this statement.

Just less than a third of responding students (50; 31%) neither agreed nor disagreed that e-assessment did not facilitate cheating, while just less than a quarter each fully agreed (38; 24%) or agreed (37; 23%) with this statement (see Table 16).

More than two-fifths of responding students (65; 41%) fully agreed that reading from a screen did not make using e-assessment difficult, while around a fifth each agreed (42; 26%) and neither agreed nor disagreed (35; 22%) with this statement (see Table 17).
Table 26. E-assessment promotes applying a variety of questions.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>26%</td>
</tr>
<tr>
<td>4</td>
<td>58</td>
<td>36%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>47</td>
<td>30%</td>
</tr>
</tbody>
</table>

Table 27. E-assessment does not facilitate cheating.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>12</td>
<td>8%</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>14%</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>31%</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>23%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>38</td>
<td>24%</td>
</tr>
</tbody>
</table>

Table 28. Reading from a screen does not make using e-assessment difficult.

<table>
<thead>
<tr>
<th>Options</th>
<th>Number of students</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Totally disagree</td>
<td>7</td>
<td>4%</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>6%</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>22%</td>
</tr>
<tr>
<td>4</td>
<td>42</td>
<td>26%</td>
</tr>
<tr>
<td>5 Fully agree</td>
<td>65</td>
<td>41%</td>
</tr>
</tbody>
</table>

Discussion

The following discussion of the results provides insight and shows originality by, similar to that of Marriott (2009), detailing students’ evaluation of the use of online summative assessment in an undergraduate ICT programming course. It further suggests implications and makes recommendations that are applicable and useful.

Some of the advantages and challenges of using e-assessment as investigated by Alruwais, et al. (2018) were confirmed in this study, with Table 3 supplying further details regarding the challenges these students experienced. In line with one of the most popular options selected in Table 5, a student confirmed that (s)he believed that having something “that you made for the” examination, “while still being able to put it on your CV is truly beneficial.” The assertion of Khairil and Mokshein (2018, p. 660) that “education is no longer limited to a certain place” was also underscored by students’ choices in Table 5, regarding not having to travel to complete their examinations.
Öqvist and Nouri (2018) asked whether coding by hand or on the computer was the better option, while in Cao, et al. (2019), a comparison of examination grading techniques in terms of choosing between paper or online was made. In answer to these questions, more than three-quarters of the students (73; 83%) preferred the online portfolio examination to the handwritten examination (see Table 4). To explain this choice, one student indicated: “I felt for this specific module, an online” examination “is more appropriate as you are applying what you learn in a relevant environment”, i.e. “coding in a coding application rather than writing code by hand or filling out” Multiple Choice Questions (MCQ) or True/False. By implication, this suggests that applicable e-assessment needs to be tailored to appropriately capture the essence of the course to be assessed.

However, several students also provided comments like “I prefer writing by hand”. One of the students, who indicated that (s)he still preferred the handwritten examination over the online examination, further explained that although it “was a great experience”, “time was flying.” Another of these students preferred “writing by hand since” (s)he was “able to revise that question that i past during writing”, while “for online once u past that question you can’t go back.” Thus, it would be applicable and useful to make recommendations that the system be updated to make it possible for students to move back to previous questions answered to revise and/or change.

Some of the students’ comments reflected mixed feelings: “Its 60/40; on the one hand, the portfolio” examination “did help us gauge our learning and capabilities” (underscoring results obtained in Tables 7 and 9); “on the other hand it doesn’t fully cover the concept of” cheating amongst students, underlining the majority of students’ ambivalent ratings in Table 16.

Results presented in Table 8 shows that meaningful e-assessment provides faculty, who are educating in the changing environment of computer technologies and applications (Goosen & Breedt, 2012), not only with a way of helping them to assess e-learning (Falkner, et al., 2020), but also with feedback to improve learning.

Emphasizing the more than a third of students, who fully agreed that e-assessment was appropriate for all subjects (see Table 12), one student observed: “It was a first and great experience. I successfully” wrote all five of my modules without any challenge. Another student, however, felt that online examinations “work for some modules; for other modules it does not!” The fact that this item showed the highest standard deviation in this study mirrors a similar result obtained in the study conducted by Alsadoon (2017).

Like that of Das, et al. (2017) the results presented for this study showed the impact of formative assessment on the outcome of summative assessment, as the bulk of the examination consisted of students’ improvements to the project they had to work on for their assignment 4.

**Conclusion**

Similar to some of the sentiments expressed by Alsadoon (2017), the purpose of the study reported on in this paper was answering the research question: What are Information and Communication Technology (ICT) students’ perceptions of e-assessment? In conclusion and answer to the question, the results presented revealed that these ICT programming students’ perceptions of the e-assessment, used to position their education towards the development
agenda in Southern Africa amid disruptions, were generally positive: The largest group of students fully agreed that e-assessment enhanced quality aspects of their learning, while just less than a third of them agreed. More than a third each of the students either fully agreed or agreed that e-assessment provided faculty with feedback to improve learning. Similarly, almost half of the responding students fully agreed that e-assessment enhances self-learning, while almost a third agreed. Finally, the largest groups of participants respectively neither agreed nor disagreed that e-assessment did not require advance technical skills from students and that e-assessment did not facilitate cheating. In this way, the article provides original insights into some of the latest and most relevant research findings on topics related to the application of e-assessment. It therefore does contribute towards scholarly debates in the field of ICT programming students’ perceptions of the e-assessment put into place to position these students’ education towards the development agenda in Southern Africa during disruptive times.

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